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AN ENGINEERING STUDY OF GLACIAL DEPOSITS AT STEEP ROCK LAKE, ONTARIO, CANADA.

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ABSTRACT.

Steep Rock Lake, in Western Ontario, was drained in 1943–44 by means of a large pumping operation. As the water line dropped, serious movements of the exposed soil occurred. Study of these, in connection with the development of the open pit from which the valuable iron ore was to be mined, led to an extensive soil investigation. The varved "clays" revealed by the mining operations with a total thickness of over 100 feet were studied first with engineering objectives in view. These "soil mechanics" investigations led to a detailed study of the soil in individual varves. Results confirm several features of the well-known seasonal theory of deposition but raise some questions which suggest the desirability of carrying still further this laboratory soil research.

INTRODUCTION.

STEEP Rock Lake is located near the eastern end of the Rainy River District, about 140 miles west of Port Arthur, Ontario, Canada (Fig. 1). The area

has long been noteworthy because of its interesting geology; many geologists have carried out intensive studies in the region around the Lake. Somewhat naturally, interest has been focussed upon the Precambrian bed-rocks. Geological literature contains a number of papers dealing with various aspects of the hardrock geology of the district (10).[1]

The existence of high grade iron ore beneath the waters of Steep Rock Lake was first suggested in 1897. It was not until 1942, however, that Steep Rock Iron Mines Limited was formed in order to develop this unusual source of iron ore. The operations of this Company had to start with the execution of some

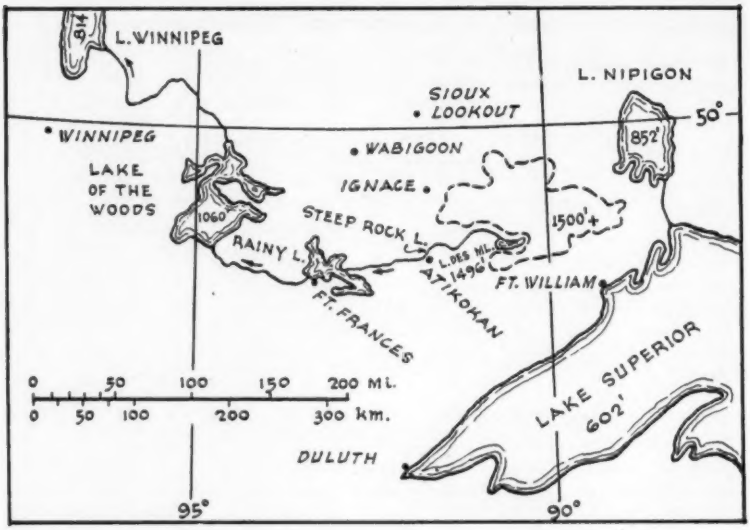

FIG. 1. Key map of location.

outstanding civil engineering works in order to divert the flow of the Seine River from the Lake, which was thereafter drained by means of a pumping operation of epic proportions (11).

The Lake had an area of about seven square miles; it was drained to a depth of over 140 feet below original water level. As the water level fell, the lake-bed deposits were exposed. At first they were unstable and many slides occurred. These drew attention to the need for a detailed study of the material constituting the lake bottom, many millions of cubic yards of which have had to be moved and controlled in connection with the open-pit mining operations (Fig. 2).

The slides revealed the varved structure of the extensive bed deposits. This has been studied concurrently with the necessary engineering investiga-

[1] Numbers in parentheses refer to Bibliography at end of paper.

tions of the soil. Even though the studies of this and other features of the local glacial geology have naturally had to be correlated with work directly related to mining operations, the authors are advised that their geological observations have revealed features of some interest. This general paper has therefore been prepared with a dual purpose in view. For geologists, it records briefly the development of the Mine after the draining of the Lake and

FIG. 2. General view of open pit workings.
FIG. 3. Section through end moraine at "esker cut."

summarizes the necessary engineering soil studies which have had to be made in achieving this result. The results of these studies appear to have some geological significance. For engineers, the paper presents a summary of the work in the field of soil mechanics necessary for the carrying out of an unusual excavation job and shows the scientific significance of this utilitarian task. Against the general background thus provided, it is planned to publish as soon as possible further detailed papers dealing respectively with specific aspects of

the engineering and geological studies. In aiming at a dual objective, the authors have had admittedly to sacrifice some of the features that are desirable both in engineering and geological papers. If, however, the rapidly expanding field of engineering geology is to be well served by written records, it would appear necessary to produce some papers of this general character.

Although not now connected directly with the Steep Rock projects, the authors were privileged to be intimately associated with its development until 1947, respectively as a consultant on special soil problems from the start of the dewatering early in 1944, and as Chief Geologist from 1940 and later Production Engineer. Their interest has continued and they have been privileged to keep in touch with developments by repeated visits since 1947. The Mine authorities have always taken a lively interest in glacial geological features, as well as in the hardrock geology which is of such direct concern to their operations, and they have kindly authorized the publication of this paper. To M. S. Fotheringham, President, to Watkin Samuel, Consulting Engineer, and to Hugh Roberts, Consulting Geologist, the authors wish to express their thanks for stimulating encouragement.

STRATIGRAPHIC SUCCESSION.

The area in which Steep Rock Lake is situated is typical of the Precambrian Shield of Canada. It consists of rolling country, with many small lakes and rivers, the exposed bed-rock being glaciated to a uniform peneplain. The lowlands and depressions between outcrops of bed-rock cradle varying thicknesses of till, sand, silt and clay. These are conformable within themselves but unconformably overlie the Precambrian.

The superficial deposits consist of glacial till or boulder clay and drift boulders presumably deposited by the continental glaciers; stratified fluvio-glacial sands and gravels deposited from melt water streams; and glacio-lacustrine silt and clay deposits laid down in lakes formed during the retreat of the ice sheets. These are all overlain by recent deposits of alluvium and peat.

LITHOLOGY.

The boulder clay consists of unsorted material composed of angular, sub-angular and sub-rounded boulders of all sizes set haphazardly in a matrix of sand, rock flour and some clay. Many boulders show well developed facets, commonly striated. The till is generally colored red-brown and contains a considerable number of hematite and limonite pebbles.

Closely associated with the till is a series of rudely to well-bedded sands and gravels presumably of fluvio-glacial origin. The material consists of water-worn pebbles and grains representing all of the adjacent bed-rock rock types. The sand and gravel deposits overlie the till.

The thickest deposits encountered anywhere in the area are the well laminated varved silts and clays of glacio-lacustrine origin. These are characterized by their regular bedding. They vary in thickness from a few feet to at least 200 feet. It is this varved material in the old lake-bed that has been

studied so carefully. A later section of this paper therefore deals with it in some detail.

Final deposition was a relatively thin mantel of unstratified alluvium, composed in part of rock flour and in part of gumbo clay. While this may be of lacustrine and fluvio-lacustrine origin, its location and character suggest that it is more likely to be a recent flood-plain deposit.

SUCCESSION OF EVENTS.

In the Steep Rock Lake area there is evidence of glacial advances from at least two directions. The earlier came from the northwest and north, probably from the direction of the Keewatin center of glaciation. The later advances were from the northeast, from the Labradorean center. The second advance was the stronger and all but obscured the original striae.

The strong Keewatin advance that deposited calcareous debris over much of the western section of Rainy River District, apparently died out before reaching the region under discussion. There are no calcareous tills in evidence. It is believed that a feeble lobe, bearing little if any material, overrode the Steep Rock Lake area and retreated without depositing appreciable debris.

The advances from the Labrador center were repetitious in nature, the original and greatest advance overriding the whole of the area, and depositing a general ground moraine. Subsequent readvances terminated farther north, forming end moraines immediately south of Steep Rock Lake and at the south ends of Finlayson and Marmion Lakes, north of Steep Rock Lake. The moraines are composed of unsorted till topped by a veneer of boulders. Associated with the retreats were glacial streams and ponds from which considerable fluvio-glacial deposits of sand and gravel were formed. These deposits are abundant south of Steep Rock Lake where kames and outwashes rest discordantly on the morainal till.

A glacial lake of considerable size and depth succeeded active glaciation. Suspended sediments carried into the Lake were deposited as varved sediments. Antevs, during his study of the deposits in 1946, recognized eight distinct series of subdivisions within the varve section (1). He accounts for the eight divisions by postulating four readvances and retreats, bringing in new volumes of silt and clay each time. The glacio-lacustrine deposits appear to be, in general, chemically and mineralogically constant for each series, indicating that the source of the materials was common. It is believed that this source was the region eroded by the Labradorean lobe. Further, it is evident from the extent of the sediments that they were deposited in a standing body of water of considerable size, Lake Johnston being the name for this suggested by Antevs. Beaches and varve material are noted at Elevations of 1275 and 1283 feet absolute, with beaches as high as Elevation 1363.

The execution of the civil engineering works associated with the development of the Mine exposed a number of sections through the superficial deposits, which have been described in general terms. The end moraine at the south end of Finlayson Lake (erroneously called an esker in local practice), for example, had to be cut through to form part of the new channel for the

Seine River. Apart from giving a remarkable cross-section through the moraine (Fig. 3), the excavation revealed no unusual features.

It is, indeed, somewhat surprising that despite all the excavation work which was carried out, only one unusual feature was observed. This is shown in Figure 4, a case of apparent faulting in the face of a gravel pit opened in a kame deposit in 1943, immediately to the south of the Lake. The usual explanation of such apparent signs of faulting in unconsolidated material is that they are the result of the melting of buried ice-blocks. Having carefully examined the exposed face shown in this photograph, the authors are unable to

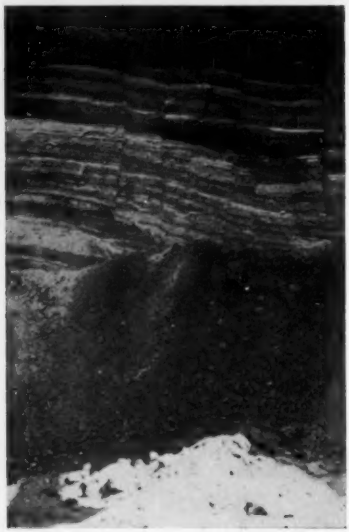

FIG. 4. Minor faulting in sand and gravel.

accept this explanation of the sharp shear failure planes. They are convinced that they constitute evidence of recent earth movement at this location, small in degree but similar in its effects to major earth deformation.

DRAINING OF THE LAKE.

The draining of Steep Rock Lake somewhat naturally revealed extensive glacial deposits. A discussion of their character consitutes the principal part of this paper. The draining of the Lake may therefore be described in some detail.

Figure 5 shows a general plan of the Lake. N-shaped, it had a total length of 15.5 miles and an original water area of seven square miles. The Seine River had its course through the Lake but by means of a large diversion proj-

ect, completed late in 1943, the river flow was led into Finlayson Lake and so into the west arm of Steep Rock Lake. A cofferdam ('D' in Fig. 5) and an existing concrete dam and power house then isolated the other two arms of the Lake, permitting the start of drainage operations.

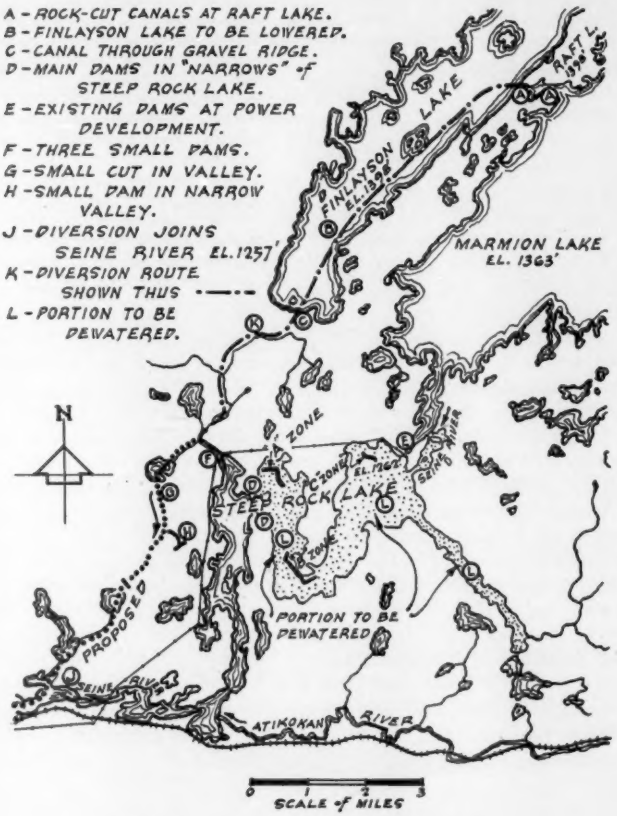
A - ROCK-CUT CANALS AT RAFT LAKE.
B - FINLAYSON LAKE TO BE LOWERED.
C - CANAL THROUGH GRAVEL RIDGE.
D - MAIN DAMS IN "NARROWS" OF STEEP ROCK LAKE.
E - EXISTING DAMS AT POWER DEVELOPMENT.
F - THREE SMALL DAMS.
G - SMALL CUT IN VALLEY.
H - SMALL DAM IN NARROW VALLEY.
J - DIVERSION JOINS SEINE RIVER EL. 1257'
K - DIVERSION ROUTE SHOWN THUS
L - PORTION TO BE DEWATERED.
N
RAFT L.
FINLAYSON LAKE
EL. 1398
MARMION LAKE
EL. 1363'
A ZONE
B ZONE
C ZONE
STEEP ROCK LAKE
PROPOSED
PORTION TO BE DEWATERED
SEINE RIVER
ATIKOKAN RIVER
0 1 2 3
SCALE of MILES

FIG. 5. General map of Steep Rock Lake.

Geophysical prospecting and intensive diamond drilling off the ice had located three iron-ore bodies beneath the bed of the Lake, designated 'A,' 'B' and 'C'. The 'B' orebody was the first to be mined but it lay beneath 100 feet of water so the pumping project was one of magnitude. Fourteen 24-inch electrically driven pumps started on the task in December 1943. By the beginning of April 1944, the water level had been lowered by about 75 feet.

Throughout the winter, the surface of the Lake had remained frozen, even though the ice cover was naturally broken. The lake-bed deposits along the more shallow parts of the Lake were similarly covered with ice and snow.

As the spring thaw progressed, however, not only was this protective frozen covering removed from the exposed bed deposits, but the melting snow from the area draining into the Lake started to run down towards the Lake. Instead of merging, as previously, into the waters of the Lake, this run-off had now to seek lower levels and in many cases seeped down beneath the shore deposits. As it emerged, it disturbed the stability of the slopes which had stood for so long under water. Many extensive "land-slides" took place and it was then that the character of the soils in the lake-bed was first revealed; it was then that this detailed study commenced.

The modern engineering study of soils has made clear that landslides can be analyzed scientifically and generally classified. Application of such studies to the mass movements at Steep Rock Lake shows that when the water-level in the Lake was drawn down relatively suddenly, the factor of safety against failure of the slopes was greatly reduced and even made inadequate. Before draw down, the effective weight of soil in the slopes was the submerged or unit weight of the material. Failure in these slopes tends to take place along a circular arc and is due to the disturbing moment produced by the weight of the segment of material within the circular arc. After the draw down, this weight was approximately doubled and this increase in disturbing moment brought about complete slipping and failure of some slopes. This type of circular arc failure was seen at various locations around the Lake.

"Mud runs" were also prevalent, and were caused by percolation of ground water from the area adjacent to the Lake. The level of the groundwater table adjacent to the Lake rose in wet periods. This resulted in an increase in the pressure of the porewater in the coarser layers of the varves. The increased porewater pressure reduced the effective pressure, and thus the shear strength of the clay, so bringing about instantaneous failures in the slopes. Slides of this nature have been fully reported in the varved clays of the Hudson Valley (8) and described by Terzaghi (12).

By the end of 1944, the water-level had been lowered by about 140 feet and it has remained at about this elevation since that time. About 520 acres of the Lake bed in the vicinity of the 'B' orebody have been exposed. About 26.5 million cubic yards of the soil have now been removed, largely by dredging and pumping. Slopes and benches have been developed in this area to an extent that has permitted the working of the ore from an open pit now 3600 feet long, and 700 feet wide, and extending to a depth of 450 feet below the old lake level. Almost seven million tons of high grade iron-ore have been removed during seven working seasons. Concurrently, study of the exposed soils has continued at the Mine and in various laboratories. The senior author carried out the early soil investigations while on the staff of the University of Toronto. During the summers of 1948, '49 and '50 a member of the staff of the Division of Building Research of the National Research Council of Canada has spent some time at the Mine especially to study the soils exposed.

LAKE-BED DEPOSITS.

As the ice and snow gradually disappeared in the early summer of 1944, the shallower portions of the old lake-bed came into view, slowly increasing in extent as the water-level was lowered by the continuous pumping. Practically the whole of the exposed area was found to be covered by a black gelatinous-looking deposit, which was extremely unstable when wet and which appeared to be organic. The material was similar to the black "ooze" which is a feature of many northern lake bottoms. Its uniformity and generally shallow depth suggested a relatively recent origin.

Since this material was quickly removed from the areas that had to be disturbed, and elsewhere quickly dried up, forming the bed for the vegetation that has been developed wherever possible as a surface stabilizer, it was not studied in any detail. Extensive shrinkage cracks developed upon drying

TABLE 1.

Sample	Moisture	Loss on ignition+	Active organic matter	Easily soluble++			
				Ca	Mg	K	P
				ppm	ppm	ppm	ppm
"Black Muck"	9.26%	17.13%	10.75%	500	35	80	trace
Grey Silt	2.4%	2.32%	—+++	800	50	100	150

+ Loss of ignition at 550° C for 7 hours.

++ Calcium and magnesium values represent water-soluble determined by turbidimetric and colorimetric methods respectively. Potassium includes water-soluble and that easily exchangeable by sodium nitrite extraction and turbidimetric estimation by cobalt-nitrite method. Phosphorus—soluble in 0.05 N HCl determined colorimetrically.

+++ Not determined, as general character of sample and low loss on ignition value would indicate little or no active organic matter.

Note: These analyses were kindly carried out by Dr. G. H. Ruhnke of the Ontario Agricultural College, Guelph, Ontario.

(Fig. 6). A chemical analysis gave the results shown in Table 1. The low organic content is to be noted in view of the black appearance of the material.

The black muck generally overlay the varved clay except along the shallow south shore of the Lake. Here sand deposits, of a few feet in thickness, were common. The sand was uniform in grain size, being obviously water deposited; in places it exhibited pronounced false bedding (Fig. 7). This would not be remarkable were it not for the fact that the direction of flow indicated by the bedding was almost exactly at right angles to that of the flow through the Lake. These sand deposits in the lake-bed were small in extent, relative to the Lake as a whole, and so are probably not unduly significant. They show, however, how complex must have been the recent geological history of this and similar regions.

Practically all the unconsolidated material in the lake-bed consisted of varved clays. These are of such importance that they are dealt with in some detail in the next section. In the stripping work carried out adjacent to the open pit, the varved deposits have in places been removed down to the under-

lying bed-rock. In a number of locations, and in all cases where there was any protuberance above the general level of the glaciated rock surface, a few feet of compact glacial till was found between the rock and the first varved material. The results of preliminary diamond drilling suggest that the till is fairly widespread over the rock beneath the old lake-bed.

FIG. 6. Black muck after drying.
FIG. 7. False bedding in sand.

No unusual features were noted in the till, apart from its striking red color. Figure 8 presents a summary of the mechanical analyses which have been made of till samples, which have been quite uniform in character.

THE VARVED CLAYS.

Practically all the soil exposed in the drained lake-bed consists of banded sediments of the type commonly described as "varved clays." This descriptive term is therefore used generally throughout this paper although, as will be

shown, it may not be terminologically exact. In the vicinity of the 'B' orebody, the scene of all the mining operations until 1951, varved clays were exposed from about Elevation 1155 to Elevation 1050. The exposures thus constitute one of the most extensive examples of varved clays on record.

Dr. Ernst Antevs was fortunately advised of the exposures and paid a brief visit to the Steep Rock Mine in the summer of 1946. The senior author had the privilege of accompanying Dr. Antevs during the first part of his field investigation and of describing to him some of the studies dealt with in this paper. With the assistance of a grant from the Geological Society of America, Dr. Antevs prepared an extensive report on the varves that he examined and in his paper was presented his interpretation of their deposition in accordance with the well known seasonal theory (1).

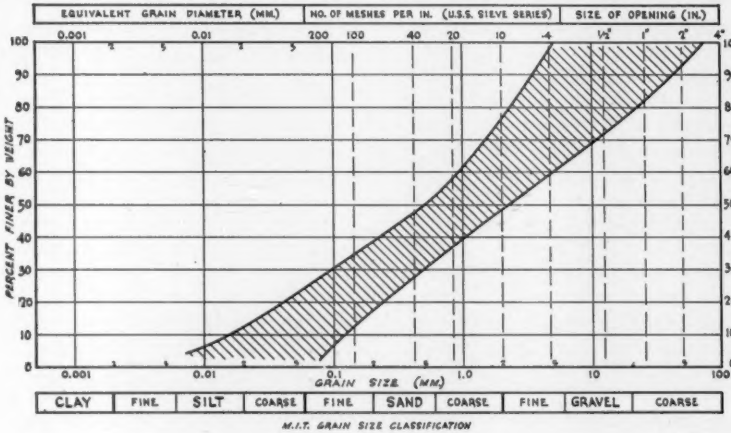

FIG. 8. Mechanical analysis chart for till.

In view of the detail with which Dr. Antevs has measured the varves throughout the complete profile that he examined, it is not necessary to give details in this paper. Attention may rather be directed to some of the features of the varving that seem to be significant in an engineering sense. Some laboratory tests that were made for engineering purposes will then be described.

The earth movements that started as soon as the lake level was lowered in 1944, and which have persisted irregularly ever since, naturally involved large volumes of the varved clays. All the major "mud-runs" that were studied were found to be due to a weakening or loosening of an underlying stratum or varve by the percolation of groundwater from the area draining into the Lake. This percolation could only be appreciable along a relatively porous band. Upon further study, it was noticed that a few thin sandy layers of widespread uniformity were to be found interspersed within the varved clays.

To the existence of these layers of sand can be attributed most of the initial soil movements that originally hampered the mining operations.

Another feature of some of the mass movements has been the exposure, after a mud-flow has occurred, of singularly smooth surfaces over which movement has taken place. To some extent these might be attributed to the effect of the moving soil upon that which stayed in place. Since, however, it is almost impossible to differentiate by eye between the soil that moves and that which does not (in the vicinity of a slide), and since the sliding surface often appears from a distance to be so clean as to be polished, it seems clear that these surfaces represent some disconformity in the deposits.

This supposition seems to be confirmed by one example, seen by the authors, in which a large mass of soil having originally a flat surface suddenly flowed through a relatively small gap, when its lower end was disturbed. When movement had ceased, a large area was exposed which appeared, even from a distance of about a hundred feet, to be a smooth glaciated rock surface, curved on its surface with a sharp edge sloped at about 45° to the horizontal. Figure 9 gives an impression of this surface.

Another significant feature (which has been found elsewhere in glacial lake deposits) is the occurrence, regularly in the lower varved deposits, of flat lens-like calcareous concretions. They are always found in the light-colored layers. These appear to have formed around nuclei and their presence suggests the existence, at the time of the deposition of the relevant varves, of water highly charged with calcium salts (see Appendix). It is of more than passing interest to note that similar concretions have recently been found in the extensive mud deposits at the mouth of the Fraser River, British Columbia. This important waterway is one of the largest rivers discharging into the Pacific Ocean. It does so through a large estuary wherein troubles with sediment deposition have long persisted. It is commonly thought that the deposition of such large volumes of sediment in the tidal part of the river is due, at least partially, to the flocculation produced by sea water. The occurrence of concretions in both locations suggests a similarity between processes of deposition.

Another feature of the varved deposits that calls for mention is the variation in color between the lower and upper deposits. All the sediments at first revealed beneath the top cover of black muck, had the dull grey color so typical of almost all clay deposits. When, however, bed-rock was approached, red coloring in the clay appeared. The lowest deposits of all were nearly as deep red in color as the orebody itself, the gradation from red to grey being gradual.

As the color of the soil changed, so did its general character, the red-colored varves being generally coarser grained than the overlying grey sediments. This variation in grain size was reflected in a number of ways, the most important from the engineering point of view being an increase in instability. When suddenly exposed to view, as by the cutting operation of the hydraulic jets used in the excavation, the red deposits frequently disintegrated rapidly for some distance back from the surface exposed. This is understandable with a silty or fine sandy soil in which the pore pressure of the entrained water is suddenly reduced.

In discussions of varved clay deposits and in detailed accounts of varved profiles much is made of the differences between different bands throughout the cross-section under study. It may, therefore, be useful to note that an equally dominant feature of the Steep Rock soils is the uniformity of many of the sections through varves that have been revealed by excavation and the extensive earth movements. Fig. 10 is typical of the appearance of many of

FIG. 9. Surface of clay exposed after a "mud-run."
FIG. 10. Cross-section through uniform varve deposits.

the exposures examined repeatedly by the authors. It will be seen that there are no "light and dark" bands, as usually reported in accounts of varved deposits. The regularity of the very thin laminations is notable. Only when dried did such material exhibit any variation between material in adjacent layers.

It must be emphasized that all the observations herein recorded are supplementary to those usually made of varved soils—the usual alternate banding, the variation in thickness of varves etc., all so ably recorded in the case of the

Steep Rock soils by Dr. Antevs. The most unusual feature of these soils, however, has yet to be mentioned, this being their behavior when disturbed. Reference has been made to the mud-flows or mud-runs that have caused many of the large mass earth movements, which originally led to such serious interference with the normal process of excavation at the Mine.

Many, if not all, of these appear to have been initiated by groundwater seepage disturbing the equilibrium of soil previously stable in the bed of the Lake. All have involved large quantities of the varved clays, some of the larger slides transporting up to half a million cubic yards of material through distances up to half a mile in the course of a very few minutes.

FIG. 11. Stream of disturbed clay.

Although evidence of movement is to be seen, incidentally, in some of the photographs that accompany this paper, Figure 11 has been included to illustrate this soil movement in a typical, although limited, example. The stream of "mud" here seen is actually flowing towards the remainder of the Lake (in the background) at a slow but quite perceptible rate. The material was that being dumped as individual bucketfuls by a mechanical "drag-line" excavator immediately behind the photographer (the senior author). This heavy machine had considerable difficulty in moving its bucket into the stiff grey varved clay that it was excavating for road construction, and similar difficulty in getting the sticky mass to shake loose of its bucket. But when once dumped, the apparently solid material "liquefied" as one looked at it and flowed smoothly away to join in the viscous stream on its way down the hill.

In an exactly similar way, when once one of the big slides or runs started, the entire mass of soil above the point of first movement appeared to become liquid and flowed rapidly, often through quite restricted openings, until the

configuration of the ground dammed up the viscous fluid. In a relatively short interval of time, the soil that had moved would again be solid.

This flow phenomenon naturally attracted attention and invited study almost as soon as the soil problems at the Mine were recognized as an integral part of the task of development. Samples were secured and laboratory tests were initiated at the Mine and the University of Toronto. These tests were carried out, in the first instance, with engineering objectives only in view. As is often the case, however, with work in the new engineering field of "soil mechanics" (a poor and unfortunate translation of *Erdbaumechanik*) the test results have not only engineering significance but also some geological interest. A brief summary of some of the laboratory work done to date on samples of the Steep Rock varved clays will, therefore, be presented next.

Despite the character of the principal soil involved, it has beeen possible to develop orebody 'B' by means of the open-pit operation originally planned. With the aid of the theory and practice of soil mechanics—in which soil is not just regarded as "dirt" but as a material that can be studied scientifically, its mass stability being susceptible to reasonably accurate analysis—the Mine authorities have been able gradually to achieve a stable working area and to minimize serious earth movements in the vicinity of the open pit. Details of this achievement are not relevant to this paper but Figure 2 gives some idea of the system of benches and flat slopes which have been developed in the course of this work.

LABORATORY TESTS ON VARVED CLAYS.

Laboratory techniques, now well recognized, have been developed in the study of soil mechanics for the investigation of the physical properties of the unconsolidated materials that play so large a part in engineering operations, and which the engineer has come to call *soil* (following, incidentally, a long geological tradition).[2] Many hundreds of samples of the varved soils from Steep Rock Lake have now been subjected to these laboratory tests, by the writers and others, so that a summary only of the results obtained can be given here.

The earliest tests were carried out for the purpose of assisting with an understanding of the prevalent mud-runs and of determining the slopes that could safely be used in excavating through the varved material in order to form the area in which the open pit could be developed. The significance of the varves was not at first apparent and so all the early soil tests were carried out on composite samples, cut through several varves indiscriminately.

These tests included several series of tests upon samples obtained from bore-holes that were put down as soon as work could conveniently be carried out on the exposed lake bottom. Twenty-seven holes were drilled to elevations as low as El. 1,080 feet, samples being taken at approximately five-foot intervals. It was the results of the tests upon these samples that first showed the great extent of the varved deposits, and which led the authors to their considerations of the problems raised by these deposits, to which this paper is but an introduction.

[2] William Smith used the word in this way as early as 1815.

The samples from these holes (which had to be sunk by the technique of wash-boring) were obtained by forcing into the undisturbed soil at the bottom of the cased hole, at the appropriate depth, a "split-tube sampler," a sampling tool described by its name. This yielded small cylindrical samples of the soil in its natural state, except only for slight surface distortion, and at its natural moisture content. Such samples are called "undisturbed" in soil mechanics work.

In all soil studies, the natural moisture content is usually an important factor. All the Steep Rock soil samples, therefore, were placed in small glass jars as soon as they were taken out of the ground, the jars being sealed immediately with wax. The natural moisture contents to be recorded, therefore, may be regarded as reasonably accurate. As the soil investigation continued, block samples of the varved material were carefully carved out at suitable locations, packed in tight fitting boxes, sealed in with wax, and shipped in this way to the several laboratories in which the soil has been studied—in Canada at Toronto and Ottawa, in the United States and in Great Britain.

The natural moisture content of a soil considered just by itself may not be of unusual significance; its importance is relative and derives from its relation to the amounts of water necessary to change the character of the soil. As convenient indicators of these moisture contents, limiting quantities of water (as first suggested by Atterberg of Sweden for agricultural soil tests) have been adapted for use in soil mechanics. These "limits" and related factors are defined as follows:

Natural Moisture Content (W_n).—The weight of water in soil in its natural state, expressed as a percentage of the dry weight of solid material.

Plastic Limit (P_w).—The weight of water required to render a dry sample of soil plastic (as distinct from crumbly), expressed as a percentage of the dry weight of solid material.

Liquid Limit (L_w).—The weight of water required to render a dry sample of soil just fluid (as distinct from plastic), expressed as a percentage of the dry weight of solid material. (These two limits are clearly arbitrary values: they are determined for any soil by relatively simple but now standard laboratory tests) (2).

Plasticity Index (P.I.).—The difference between the liquid and the plastic limits, thus automatically expressed as a percentage of the dry weight of soil; it is a good indication of the range of plasticity of a soil.

A number of ways have been suggested for interrelating the limit values and the natural moisture content of a soil. Possibly the most convenient is the water plasticity ratio which, using the symbols shown above, is expressed as:

$$B = \frac{W_n - P_w}{L_w - P_w} \quad \text{or} \quad \frac{W_n - P_w}{\text{P.I.}}. \tag{5}$$

The relevance of these factors becomes clear when the records of tests upon soil samples from the bed of Steep Rock Lake are examined. Figure 12 is a graphical summary of test results for samples from a typical deep bore-hole through the varved material. It shows for each sample tested its natural

moisture content, liquid and plastic limits, plasticity index and water plasticity ratio. The samples were cut without any attempt to separate the varves and are therefore composite in character.

Examination of the chart will show that, in the case of every sample tested, the natural moisture content was above the corresponding liquid limit. Not only so, but the difference is in every case so appreciable as to eliminate any possibility of this surprising feature being the result of experimental error. Several hundred soil samples from Steep Rock Lake have been tested; in practically every case, the same high natural moisture content was found.

This feature of the varved material raises some academic questions but it had an immediately practical application when first discovered. It explained the character of the extensive slides, or mud-runs, which have already been described. Once such material is disturbed, the bonds of the clay-water systems are broken, at least in part, thus leading to liquefaction of the disturbed mass, which will then flow until impeded by some obstacle, the excess water draining away, leaving the soil in a relatively much more stable condition than it was originally. In order to achieve proper stability for the purpose of developing the open-pit iron ore mine, it was, therefore, clearly desirable to keep all disturbance of the natural soil to an absolute minimum. This requirement has been closely followed by the Mine authorities since its necessity was fully recognized, even to the extent of controlling most of the groundwater seeping into the old lake basin from the small rocky drainage area around, seepage that was a potent cause of some of the early major slides.

The dimensions of the slopes and berms which have been developed as the open pit area has steadily been extended, have been calculated on the basis of what may simply be called "strength tests" upon undisturbed cylindrical samples cut from block samples of the varved soil. In this form, the soil has the consistency of soft cheese. It can be cut fairly easily, with suitable trimmers, but even when handled in this way, it does not usually indicate the excess water that it contains. Only when a sample is actually "re-moulded" in the fingers does one feel the sudden change in consistency. A peculiarity of the trimming of samples may usefully be noted. In many cases, cutting of a block sample would reveal a "blocky" structure to the mass, the sample breaking naturally into irregular prisms with major axes from one quarter to one inch in length. This structure would be shown while samples were being roughly trimmed, when natural fracture could take place along such random planes, before more careful and accurate final trimming was carried out. Beyond this feature, the strength tests revealed nothing of special significance to this discussion.

In all this early laboratory work, samples were obtained and tested without regard to the laminated divisions provided by the varves. For practical purposes, it was the action of the soil in the mass that had to be studied. As work progressed, however, and as the immediately urgent practical questions were gradually answered, attention was focussed to an increasing degree upon the relative properties of the light and dark varved material, and finally upon the variations of soil properties within individual varves.

The next group of tests were also performed initially, however, upon what may be called "mixed samples," i.e., with no attempt to separate individual laminae. These tests consisted of accurate determinations of the particle-size distribution curves for a large number of samples. In the technique of soil mechanics a convenient method is now almost universally used for this purpose, derived from a simple version of the same test developed for agri-

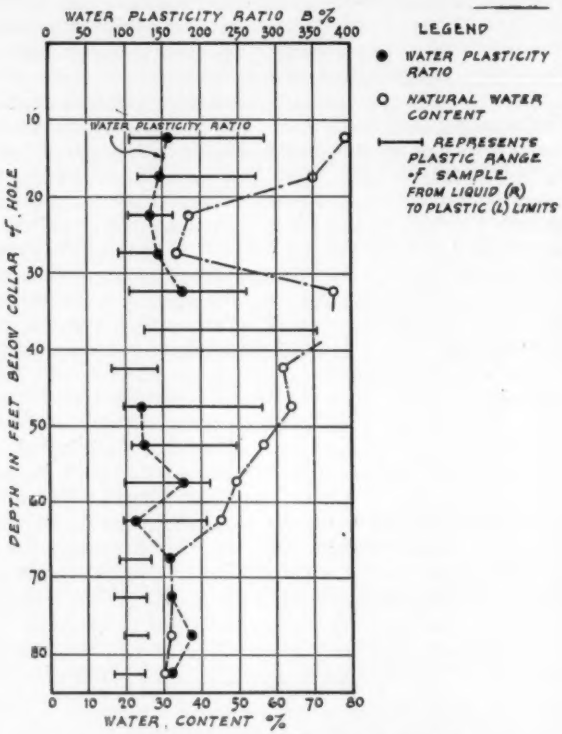

FIG. 12. Log of typical deep bore hole.

cultural soil studies by G. J. Bouyoucos (2). A soaked sample, carefully weighed, is thoroughly mixed with distilled water to make a suspension of 1,000 cc. A specially sensitive hydrometer is then inserted in the suspension at specific time intervals. From the values it gives for the specific gravity, the particle-size distribution is calculated. It is of some significance to note that a suitable deflocculating agent is added to the suspension before final mixings and that, at the end of the usual 24-hour duration of the test, a few

drops of hydrochloric acid are usually added in order deliberately to flocculate the fine particles still in suspension after this interval.

Results are generally plotted on special semilogarithmic forms similar to that used for Figure 13. On this diagram has been plotted the envelope of all the mechanical analyses of Steep Rock varved soils carried out by the senior author and by members of his staff. Equally of note is the relatively high percentage of soil particles in the Steep Rock varved soils which are below 0.002 mm. in equivalent diameter.

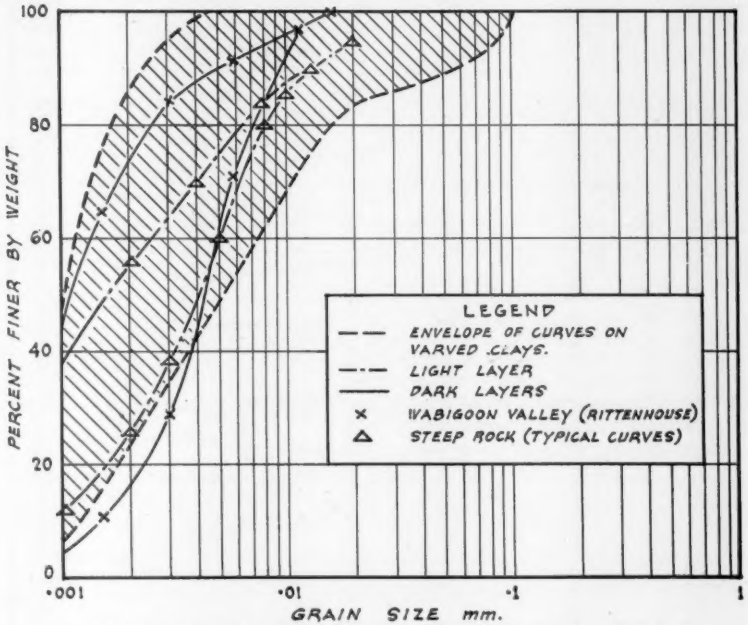

FIG. 13. Envelope of mechanical analysis curves for all clay samples.

The first mechanical analyses to be made (by R. F. L.) on material from individual varves were somewhat roughly carried out and suggested that there was little significant difference between the particle-size distribution in the dark and light bands. Subsequent tests, more carefully carried out, notably by H. B. Sutherland and W. J. Eden, have showed a definite and consistent difference, although still within the confines of the envelope shown in Figure 13. Typical curves have been plotted on the chart for dark and light bands and, for comparison, similar typical curves obtained by G. Rittenhouse in the only comparable investigation known to the authors.

Rittenhouse studied an unusual series of varved clays that he found in the Wabigoon Valley, in the district of Kenora, Western Ontario, not more than

80 miles from Steep Rock Lake. The reported abnormality included a dark red color for a series of thick dark varves, which appears to be very similar to the same feature that is so common in the lowest of the Steep Rock deposits. Rittenhouse reports mechanical analyses carried out by the pipette method; two of these have been plotted (9).

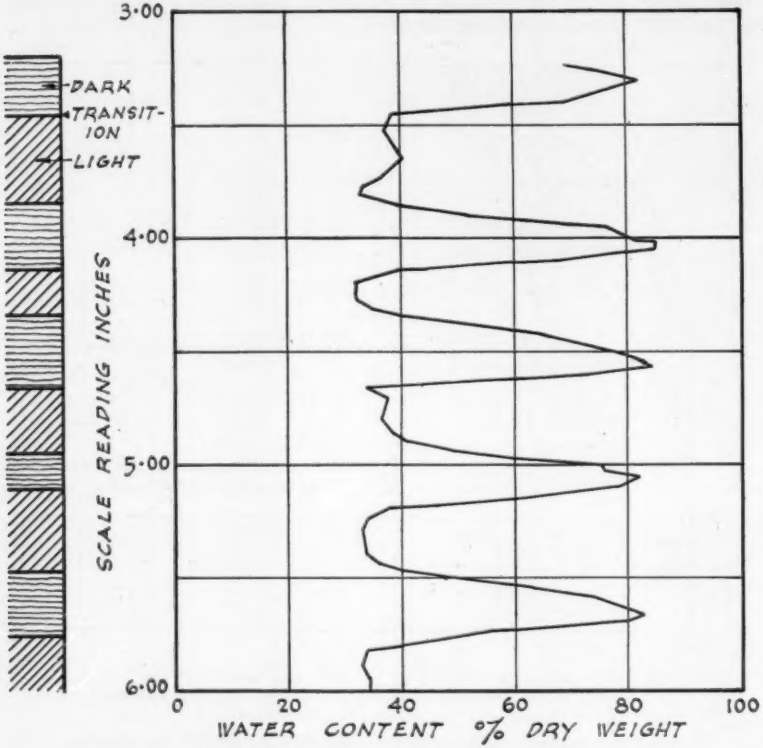

FIG. 14. Variation of moisture content within varves.

In a private report, H. B. Sutherland has summarized his findings regarding mechanical analysis of the varved materials by recording that, for the samples he analysed, 50 percent by weight of all the dark laminae tested was smaller than 0.002 mm. in equivalent diameter, whereas only 10 percent of the particles from the lighter varves were of the same order of magnitude. Variations in particle-size distribution within the varves have also now been studied. It is yet too early to report upon these variations in detail but it can be recorded that, in the samples so far studied, there does not appear to be any

general gradation, uniform or otherwise, from top to bottom of the varve. Only in the case of the coarse red silty and sandy material found close to the rock, has any such gradation been detected, and even in this case, the gradation is not well defined and might even be explained by errors in sampling. The application of the refined methods of sampling and analysis may yet demonstrate that gradation does occur within laminae; variations in natural moisture content have already been detected.

Figure 14 shows some preliminary results from a detailed study of the natural moisture contents of light and dark laminae, carried out by W. J. Eden. As in the other tests reported, there is a marked difference in moisture content in adjacent laminae. Correlation of these differences with differences

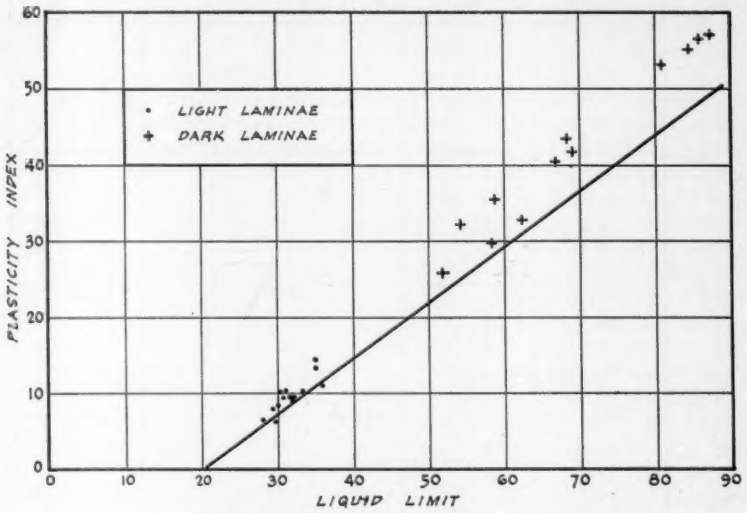

FIG. 15. Chart of liquid limit and plastic limit relationship.

in particle-size distribution appears to present a promising line of further inquiry. Difficulties in sampling and testing the necessarily small quantities of soil involved have impeded progress, but the work is continuing.

The plasticity of the samples tested calls for comment. It has been found that the plasticity of fine-grained soils is related to their clay content, i.e., not just to the clay-sized particles but to the actual properties of the clay minerals contained in the soil. The property of plasticity is thus a useful indicator of soil type and it is so used in the engineering study of soil. Graphical methods are again in common use as a useful means of presenting plasticity data. Figure 15 shows the relation between the plasticity index and liquid limit for some of the Steep Rock samples. A difference between the plasticity of the material in light and dark laminae will be at once apparent. That from

the light laminae is almost all close to the classification of inorganic clays and silts of low plasticity, whereas that from the dark laminae is seen to be in the range of clays of high plasticity. Figure 16 presents a similar relationship between the Plasticity Index and the percentage of particles smaller than two microns (0.002 mm.) in corresponding samples. Again, there is a marked difference.

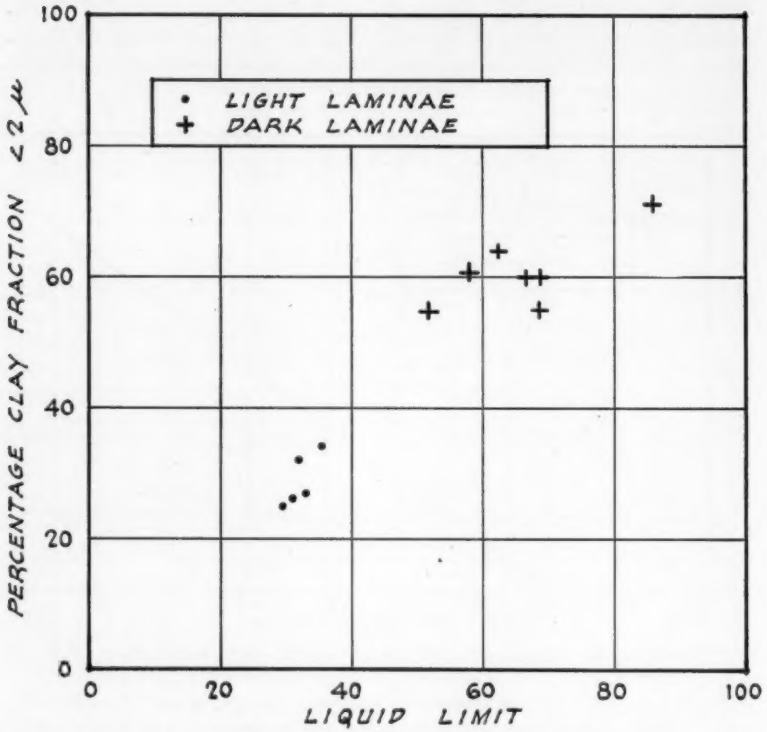

FIG. 16. Chart of liquid limit and particle-size relationship.

It will be clear that the study of these varved clays in the laboratory has already proved to be an extensive undertaking. A summary only has been here presented of work which has extended, intermittently, over a period of about five years. Amongst other tests that should at least be mentioned are the examination of soil particles by means of an electron microscope, and simple tests for thixotropy. The electron microscope photographs appeared to show rounded particles, suggesting a preponderance of fresh minerals, but this evidence is inconclusive at present. The thixotropy tests show also a

difference between the characteristics of the light and dark varved material (3). Further investigations are in progress and it is hoped to study the mineralogical character of the soils in some detail.

SOME COMMENTS.

So much factual information has been presented in summary form in the foregoing pages that some general comments may usefully be presented in conclusion. Inevitably, these comments raise some questions since they relate to the complex phenomenon of the deposition of varved material.

The authors are familiar with the well publicized theory of annual deposition of De Geer and have studied the relevant literature. Since an extensive bibliography accompanies Antevs' recent paper (1), to which this paper is, in a sense, a companion, it does not appear to be necessary to repeat any such extended list of references.

Apart from the paper by Rittenhouse, and one by Fraser (7), however, the literature does not appear to contain any record of an approach to the problem of varve deposition by way of such laboratory soil tests as have been here described. It may therefore be useful to point out how the results of these tests lead to some conclusions similar to those derived from geological reasoning and to invite attention to some further questions that the test results suggest.

(1) The natural moisture content of the varved material calls first for comment, not only because of the lack of any tendency for it to decrease with depth (for mixed samples), and the almost constant value for the water-plasticity ratio with increasing depth, but also because of the variation between the water naturally retained in the light and dark laminae respectively.

(2) The variation of the natural moisture content of the varved material is partially explained by the variation between the plastic properties of the light and dark varved material. The essential differences between the two types of material are shown clearly in Figures 15 and 16. It is generally assumed that the more plastic is a clay-sized soil, the more the contained particles consist of the clay minerals. It can not be doubted but that this finely divided material is the product of glacial action, at least in part, originating as rock flour, which would be expected to display very low plasticity. What is not clear is how such a marked increase in plasticity, as is shown between light and dark varves, and therefore in mineral transformation, could take place in annual periods or, alternatively, could vary so regularly at semi-annual intervals. The difference so strikingly shown in Figure 15 can only be explained mineralogically, or by base exchange. It is not clear how such a significant change in the basic character of soil solids can be related merely to seasonal deposition.

(3) It may be pointed out that the light banded material is more coarsely grained and that this will explain the difference in plasticity, but the difference in particle-size, although definite, is still slight. In this same connection, it has already been noted that a relatively simple sedimentation test is used, in

soil mechanics, for particle-size determination. By means of the theory of this test it is possible to calculate the time required for soil particles such as those at Steep Rock to settle in still water. Particles, for example, having an equivalent diameter of 0.001 mm. in water at a temperature of 35° F will settle in 180 days only 28 feet. And not only does more than half the material in the dark varves consist of particles of this size or smaller, but the estimated depth of the glacial lake was over 300 feet.

In some discussions of varved depostion, circulation of lake waters due to thermal gradients is suggested. If there is circulation of any kind, there must be some other factor affecting deposition because the carrying power of moving water would effectively offset even the slow settling of the fine particles, since the velocity could not have been vertically downward at the lake bottom. There appears to be no gradation in particle-size throughout the section of a lamina. If, however, the soil material in a varve is dried, ground up, soaked in distilled water and subjected to the usual sedimentation test for particle size, it will gradually settle out with perfect gradation—from the coarser particles at the bottom to the very fine particles that remain in suspension.

(4) It is clear that some process in addition to ordinary sedimentation must have been operative when the varves were formed. Some indication of this is given by the consistently and "artificially" high natural moisture content of the varve material, a characteristic alien to sediments deposited by straight settling. From the description given of the soil, it can be seen that it must have a "honeycomb" type of particle structure, in order for so large an excess of water to be present without being evident. This would seem to be possible only if there existed some kind of interparticle attraction during deposition. This, in turn, suggests the phenomenon of flocculation. It is not without significance that, in conducting mechanical analyses of Steep Rock soil samples, it is almost always necessary to add hydrochloric acid to the 1,000 cc. suspension, even after it has stood for twenty hours, in order to precipitate, as a flocculant, the very finest particles still remaining in suspension. Correspondingly, more than the usual dispersing agent is required at the start of these mechanical analysis tests in order to break up the soil into its constituent particles.

(5) Recent experience at the Mine is related to this same feature in a practical way. Material from the lake-bed at the "A" orebody is now being pumped into the one section of the Lake that remains at its original level (the west arm). Through this large expanse of water, the Seine River now flows but at negligible velocity because of the large cross-section of the water area. Despite this, some material—pumped from its varved position—is picked up by this very limited flow of water, carried to the foot of the Lake and then down the old course of the Seine River for a distance of at least 50 miles without settling out, passing through many smaller lakes on the way. Tests have shown, however, that most of the soil that is pumped fails to break up into its constituent particles even in passing through the pumps, but is deposited after discharge in particle-assemblages that correspond in size to chemically formed flocs.

(6) Flocculation involves electro-chemical action. Similar action must have been involved in the formations of the concretions that are found in the light layers of the Steep Rock soils. Also of significance, in this connection, is the blocky structure of the soil despite its laminated nature. The senior author has seen exactly the same type of structure developed in a clay slurry that had been subjected to treatment by electro-osmosis. Sudden precipitation of river sediments when sea water is encountered is an associated phenomenon, even to the formation of concretions, as in the Fraser River estuary. It has been noted that the Steep Rock varved material has, when wet, a bleaching effect upon colored clothing material, thus further substantiating the idea of sediment flocculation.

(7) Study of these facts suggested that possibly something could be gained by reference to studies of other natural banded deposits. As is well known, discussion still continues regarding the exact origin of some of these. It is of interest, however, to note that in an extensive study of the radiolarian cherts of California (to which attention was kindly directed by Dr. H. H. Aldrich), E. F. Davis discards the idea of a rhythmical annual deposition (6). Opinion seems to favor either the idea of regular deposition from supersaturated suspension or the concept of rhythmic segregation of colloidal silica.

(8) The authors are aware that the concepts of flocculation, and of supersaturation, have been associated with the generally accepted theory of varve deposition. One of the clearest expositions which they have encountered in their studies is in a very short paper by E. M. Burwash (4). It is in a volume of a series not usually considered in relation to geological literature and so is reprinted, by permission, as an Appendix. The idea of climate is prominent, as usual, in this explanation, and it is this feature that the writers find difficult to correlate with their field observations. In addition to features already mentioned, they have seen an exposure of about 30 feet in depth in which the varves were all of identical thickness. Has climate changed, through the years, to the extent that such perfect regularity is just a thing of the past?

(9) Many details of the Steep Rock varved exposures raise other questions, although not usually of so general a character as those already noted. One of these should, however, be mentioned, this being the repeated exposure of very thin laminations all of a uniformly light grey color with no evidence at all of inter-bedding by darker material. Unfortunately, it has not yet been possible to make detailed studies of samples from these locations but their existence raises further doubts as to the climatic variations of the past being such as to eliminate entirely a long series of winters.

(10) Finally, possibly the most striking of all the observed features of the varving in the field are the remarkable distortions in the varving regularly to be observed. The first that the writers observed were near the surface of the lake-bed deposits and included almost complete "folds" of groups of varves. The action of surface ice seemed to be the only possible explanation of this phenomenal distortion. Later, far from the shore line, and well below the level of the recent lake bottom, similar distortions were again seen. A

vaguely possible explanation of these seemed to be the sliding in from the sides of material of the same age when the varves in question were at lake-bottom level. More recently, however, deep-seated distortions have been exposed, far removed from any shore line, far below the recent lake-bed level, and amid large areas of quite level varves. Figure 17 is a typical exposure.

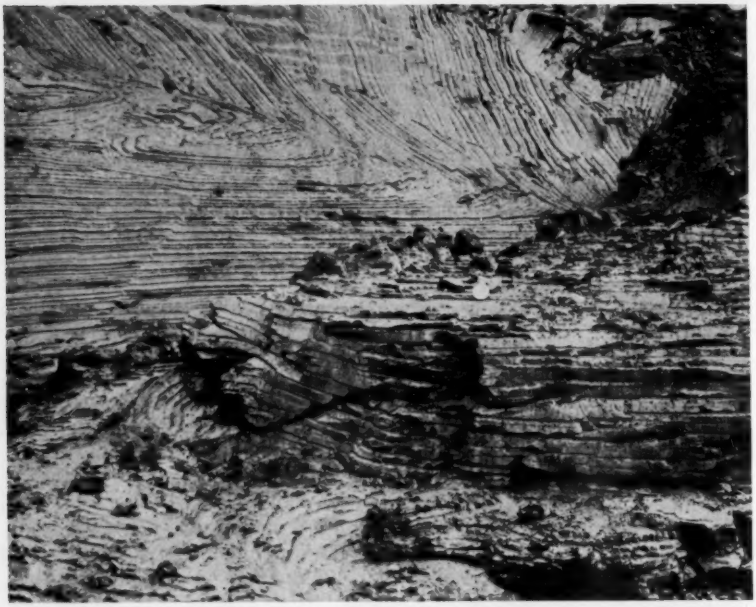

FIG. 17. Deformation in varves.

CONCLUSION.

The foregoing comments indicate clearly the stimulus which the study of the Steep Rock soils has given to the thinking of the authors and all others who have worked with them in this investigation. In all these studies, not only have they had the benefit of discussion with the Mine officers, notably those previously mentioned, but also the active co-operation of Ben Eyton, Chief Chemist of Steep Rock Iron Mine Limited, and, through the Division of Building Research, National Research Council of Canada, of W. H. Ward of the British Building Research Station, H. B. Sutherland now of the University of Glasgow (who spent the summer of 1948 at the Mine), and F. L. Peckover and W. J. Eden of the Division's Foundations and Soil Mechanics Section, other members of which have contributed much in discussion and in test work. Laboratory studies of the varved soils continue at each of the

institutions mentioned and it is hoped that more detailed accounts of some of the features mentioned generally in this paper may soon be available.

DIVISION OF BUILDING RESEARCH, NATIONAL RESEARCH COUNCIL,
OTTAWA, CANADA,
AND PORT ARTHUR, ONTARIO, CANADA,
May 2, 1953.

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APPENDIX.

An explanation of varve formation by E. M. Burwash from his paper "The Deposition and Alteration of Varved Clays," Trans. Royal Can. Institute, vol. XXII, p. 3–6, Toronto, 1938.

As water cools, its capacity for the solution of gases increases. The water of a frozen lake therefore is more highly acidulated by absorption of carbon dioxide than the warmer water of the summer which at present ordinarily rises to a temperature of nearly 60° F. The solution of calcium carbonate in the water depends on that acidulation, and its deposition from the water probably on a decrease in the acidulation, which would be brought about by a warming of the water. On this basis we can perhaps correlate the deposition of the varves with the seasonal changes which must have been taking place at the time of the sedimentation.

(a) During the winter, the surface of the soil is frozen and precipitation remains upon it in the form of snow. Any slight liquefaction of the snow is frozen before it has time to run off in the form of drainage. It cannot penetrate the frozen upper layer of the soil. Underneath the frost layer, the unfrozen ground water continues to work its way slowly into the streams and lakes, carrying with it no solid sediment, but a considerable supply of dissolved salts, especially calcite. The

cold acidulated water of the lake is well adapted to receive these, and retain them without precipitation, so that a condition of saturation is approached, perhaps nearly reached.

(b) With the arrival of spring the ice-cover of the lake melts more slowly than the snow on the adjacent land. The floods that follow the liquefaction of the snow and the thawing of the surface soil carry large amounts of solid sediment into the lake. The coarser parts are deposited near the shores, while the finer clay is carried further out and settles gradually over the bottom of the lake for great distances, covering the bottom of even large lakes. The floods once over, the streams become clear, much reduced in volume, and the amount of silt carried out is negligible.

(c) As the lake waters gradually warm by direct solar radiation and conduction from the air after the disappearance of the ice, and are further warmed by the inflow of warm surface waters, the capacity of the water to retain carbon-dioxide is decreased, and the deposition of part of the solids dependent on its presence would follow. This includes all carbonates but mainly calcite. The actual condition is that the water in the depths of the lake remains colder all summer than that on the surface. As is well known, the species of fish that prefer cold water are then found at a considerable distance below the surface. The calcite released from solution in the warmer water near the surface would sink until it came to the colder and more acidulated depths which would redissolve it, become saturated, and finally deposit calcite as a precipitate at the bottom. We may therefore refer the formation of the white partings in the clay to the summer season. The predominantly argillaceous layers must also be conceded to contain some calcite, apart from the presence of numerous calcareous concretions in them.

SOME CONSIDERATIONS REGARDING LIQUID INCLUSIONS AS GEOLOGIC THERMOMETERS.[1]

B. J. SKINNER.

ABSTRACT.

The stability of liquid inclusions in a Brazilian quartz crystal has been investigated. The quartz was subjected to high external water pressure which caused water to move into the vacuoles. Liquid was forced out of the vacuoles by heating the quartz above the temperature at which the vacuoles were just filled. It is suggested that the amount and composition of liquid in vacuoles depend on ambient pressure and temperature and, therefore, may vary during geologic time.

INTRODUCTION.

THE use of liquid inclusions as geologic thermometers has recently become very popular. Vacuoles in minerals are generally filled by a liquid and a vapor bubble of unknown composition. Inclusions containing three phases, solid-liquid-vapor, have been reported by Bailey and Cameron (1),[2] and liquid-liquid-vapor by Cameron, Rowe and Weis (4).

Most workers assume that the temperature at which the vacuoles are just filled by a single liquid phase is the minimum temperature of formation of the mineral. Liquid in the vacuoles expands and the vapor bubble shrinks as the mineral is heated. The temperature of formation can be calculated from the temperature at which the vapor bubble disappears if the pressure at the time of formation is known. The filling temperature is defined as the temperature at which the liquid phase just fills the vacuole and this term will be used throughout the paper.

Criticisms and cautions regarding interpretation of results have been previously suggested by Kennedy (6), Bailey and Cameron (1), Cameron, Rowe and Weis (4), and others.

Temperature determinations from three-phase inclusions are less certain than those from two-phase inclusions. Insufficient evidence on the composition of the phases, and on their relation at the time of formation of the vacuoles, means that interpretation of results from three-phase inclusions is highly speculative.

Much faith has been placed in the basic assumptions of the method. The two most important assumptions are,

(1) The vacuoles were completely filled at the time of formation by a single fluid of the same composition and density as the depositing solution.

(2) The quantity of liquid in the vacuoles has remained essentially unchanged since the time of formation.

[1] Paper No. 134 published under the auspices of the Committee on Experimental Geology and Geophysics and the Division of Geological Sciences at Harvard University.

[2] Numbers in parentheses refer to Bibliography at end of paper.

The validity of the first assumption is at times doubtful. Sorby (8) made a detailed study of liquid inclusions in synthetic crystals. He produced vacuoles initially filled by two phases when he varied the phase of the solution from liquid to gas during the growth of the crystal. Cameron, Rowe and Weis (4) have pointed out that the first assumption is reasonable for vacuoles in minerals known to have formed from solutions at low temperatures. They further point out that pegmatite minerals may have formed under conditions with two or more fluid phases present, in which case the first assumption is unwarranted.

The second assumption seems even less justified. Experiments, reported in this paper, have been conducted to measure the movement of fluid into, and out of, vacuoles in a quartz crystal.

INSTRUMENTATION AND TECHNIQUE.

A large, well formed Brazilian quartz crystal was generously lent by the Department of Mineralogy of Harvard University for the present investigation. The quartz was a colorless, transparent, single crystal, which exhibited no fracture or sign of strain.

The crystal measured 27 cm by 18 cm across the base. A complete section of the base, approximately 1 cm thick, was cut perpendicular to the c-axis. The slice was then marked out on a 2.0 cm grid giving 120 squares, or parts of squares, where terminated by the crystal faces. The plate was next cut into the 120 squares marked out by the grid lines and each square numbered and oriented. From each square a thin plate was cut, approximately 2.0 mm thick. The plate was reduced to a thickness of 1.5 mm by careful grinding, followed by hand polishing on a glass plate.

Vacuoles were abundant in all parts of the crystal, averaging 50 per cubic cm. The filling temperatures of the vacuoles in the plates were measured by immersing the plates in a heated silicone liquid. A special heating stage, designed and constructed by J. K. Grunig, was used for the study.

The silicone liquid, produced by General Electric, Reference No. 9996–500 OX, was contained in a cylindrical glass vessel three inches in diameter. The glass vessel was seated centrally in a cylindrical asbestos shield five inches in diameter (Fig. 1). The space between the glass cylinder and the asbestos shield was filled with an insulating mixture of asbestos wool and magnesia powder. The top of the asbestos cylinder was covered with a circular sheet of asbestos with a two-inch diameter hole cut in the center. The asbestos lid kept the glass vessel containing the silicone liquid in position.

The asbestos shield was attached to a rack with two calibrated horizontal motions. The movable rack was bolted to the microscope stage and the whole assemblage could thus be moved in a horizontal plane, independent of the microscope.

The quartz specimen was placed on a circular glass disc, which was suspended on an adjustable brass framework within the glass cylinder. The brass framework could be tilted through 10°, which allowed the vapor bubble in the vacuole to be moved into an advantageous position for observation.

A second glass vessel, two inches in diameter, and with an optical surface ground on the bottom, was suspended in the larger glass vessel and fitted snugly against the opening in the asbestos cover. The smaller glass vessel came into contact with the silicone liquid, completely sealing the heating cell once the specimen was in place.

Thermocouple and heating element leads were led down the gap between the two glass vessels through holes drilled in the asbestos cover.

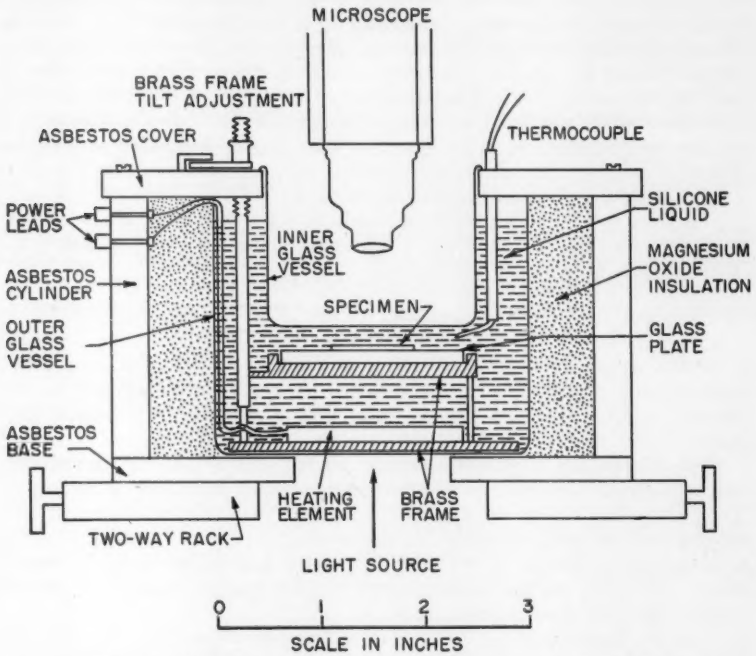

FIG. 1. Diagram of heating stage (designed by J. K. Grunig).

The silicone liquid was heated by a platinum resistance element wound across a circular insulating ring one and three-quarter inches in diameter. The heating element was placed on the bottom of the larger glass vessel one-half inch below the glass plate holding the specimen.

The specimen was viewed under transmitted light. The light from a 250 watt tungsten bulb entered the heating cell through a one and a half inch diameter hole cut in the center of the two motion rack and illuminated the specimen from below. The specimen was observed with an adjustable microscope under magnifications of 25 ×, 75 ×, or 100 ×.

The temperature of the platinum resistance element was regulated by an unbalanced alternating current bridge and thyratron circuit. For details of this type of circuit see Bancroft (2). Temperature was controlled to ± 1° C with this circuit. Measurements were made by reading the emf of an alumel-chromel thermocouple on a Leeds and Northrup Type K potentiometer.

Measurements with a thermocouple probe showed that with heating rates of 1° C per minute or less, temperature inhomogeneities within the liquid were never greater than 1° C.

A standard technique was employed throughout the work. The temperature of the bath was quickly raised to 80° C, allowed to come to equilibrium, then raised at the rate of 0.5° C/minute. In this way the vacuole filling temperature could be obtained accurately to within ± 0.5° C. Slower rates of heating did not affect the filling temperature, indicating that any temperature difference within the quartz plate was less than 1° C. Results were reproducible on individual vacuoles to within 0.5° C over a number of separate observations, provided the temperature was never raised more than a degree or two above the temperature of filling.

Each vacuole was measured separately at least two times to make sure that no leakage had occurred before the vacuole filled and only successive results agreeing to within ± 0.5° C were accepted.

DISTRIBUTION OF VACUOLES.

Plates were carefully examined and as many as 15 vacuoles selected for measurement in each one. Every vacuole was located by coordinates on the two-way stage. Vacuoles selected were well within the plate where they would be free from surface fractures developed during grinding.

The distribution of vacuoles seemed random throughout the crystal and only in a very few cases could an actual plane of liquid inclusions be identified. The diameter of the vacuoles ranged from 0.05 to 1.05 mm. Their shapes ranged from the sharp, straight outlines of negative crystals with an obvious crystallographic control to vacuoles with rough and highly irregular boundaries. Vacuoles studied were selected to give equivalent numbers of the various size and shape modifications.

Negative crystals, with a definite crystallographic orientation, were always platy, with a long dimension of 0.05 to 1.50 mm and thickness of 0.05 to 0.25 mm. In general, irregular vacuoles were equidimensional, ranging from 0.05 to 0.85 mm in diameter. A few highly irregular, branching vacuoles consisting of small equidimensional volumes were connected by thin, tubular appendages. These branching vacuoles were always large, from 0.75 to 1.25 mm in their longest dimension and from 0.25 to 0.40 mm in thickness.

Some vacuoles are possibly of secondary origin and were not considered in the study. Filling temperatures of the secondary vacuoles fell within the same range as those of the primary vacuoles but in most cases the secondary vacuoles leaked during heating. The secondary vacuoles generally lay in recognizable planes and were always lath-like. Their dimensions ranged from 0.10 to 0.55 mm in length, 0.02 to 0.10 mm in width and 0.01 to 0.05 mm in

thickness. Many of the planes of secondary inclusions cut across a large primary vacuole, in which case the primary vacuole also leaked during heating and was not considered in the study.

The problem of differentiation between the primary and secondary vacuoles was apparently not as difficult in this case as in minerals of metamorphic and igneous rocks, since the crystal had grown in an open vug. Cameron, Rowe and Weis (4) have considered the problem of primary versus secondary vacuoles thoroughly. They believe, in the case of pegmatitic quartz, that disseminated negative crystals are probably primary vacuoles. In the Brazilian quartz used in the present study only the lath-like inclusions described above were considered secondary. The possibility of misinterpretation is fully recognized.

Vacuole filling temperatures and movement of water into and out of the vacuoles were of the same order of magnitude whether the vacuoles were recognizable negative crystals or irregular openings.

EXPERIMENTAL RESULTS.

Twenhofel (10) reported a zonal arrangement in the filling temperatures of liquid inclusions in a fluorite crystal from Luna County, New Mexico. It was hoped that the present investigation would reveal a similar zonal arrangement in the Brazilian quartz crystal. Traverses were made across the

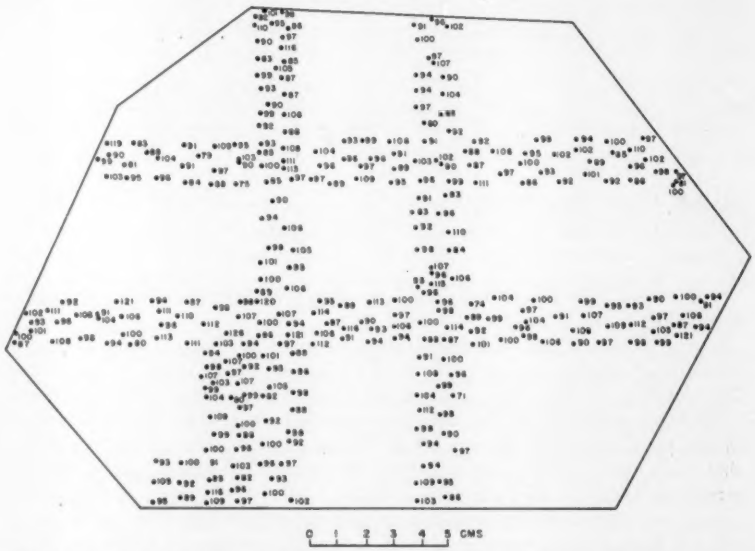

FIG. 2. Diagram showing position of vacuoles studied and their temperature range. (Four traverses across the crystal.)

crystal to test the possibility. No zonal arrangement was apparent. The same range in the vacuole filling temperature was found throughout the crystal (Fig. 2). Examination of the different types of vacuoles also showed an unexplained spread of temperatures. The average of the readings throughout the crystal was 97° C with an equal spread of temperatures on either side of the average ranging from 74° to 126° C. Approximately 60 percent of the readings fell in the range 90° to 102° C.

Previous workers have noted that erroneous results were obtained when the vacuoles leaked during heating. Most writers, however, imply that only those vacuoles near the surface are affected by leakage, suggesting that shallow fractures developed during cutting and grinding, and that vacuoles well

TABLE 1.

EFFECT OF INTERNAL PRESSURE ON THE FILLING TEMPERATURES OF VACUOLES.

Longest diam. of vacuole, mm.	Filling temp. before heating, °C	Temp. of run, °C	Time of run, hours	Filling temp. after heating, °C	Maximum pressure, bars	Pressure remaining after run, bars
1.00	101	122	3	118	325	50
1.00	105	122	3	112	270	155
0.50	88	122	3	110	540	185
0.40	93	122	3	106	415	250
0.20	98	122	3	109	385	200
1.50	109	128	20	124	330	80
1.00	99	128	20	112	495	270
0.75	100	128	20	120	480	145
0.50	96	128	20	115	535	230
0.50	97	128	20	108	510	240
1.00	97	121	110	119	390	15
1.00	104	121	110	117	260	50
0.75	99	121	110	108	350	200
0.60	103	121	110	111	280	150
0.50	92	121	110	114	410	100
0.30	98	121	110	118	360	40
0.25	97	121	110	109	390	190

below the surface do not leak, nor have they lost any fluid since the time of formation.

In a series of runs, individual vacuoles were carefully observed and the temperature raised from 20° C to 30° C above their filling temperatures. The plates were then held at the raised temperatures for a number of hours. Care was taken that all the vacuoles so treated were well below the surface of the plate, that they did not lie in a recognizable plane of inclusions and that there were no flaws or cracks in the vicinity. Typical results are presented in Table 1. Column two of Table 1 records the vacuole filling temperatures before the run, and column five the filling temperatures after the run. The figures in column six are the maximum possible pressures developed in the vacuoles by expansion of the liquid, assuming no liquid had escaped. In column seven, the pressure remaining in the vacuoles at the end of the run

is given. The pressure values were obtained by assuming the liquid in the vacuoles to be pure water and using unpublished low temperature P-V-T data for water provided by G. C. Kennedy.

With a heating rate of 1° C/minute, the vacuoles did not break due to the increased water pressure within them and the fluid apparently escaped along lineages. Readings were repeated before and after runs at least three times and in every case agreed within ± 0.5° C.

The plates were allowed to stand for six weeks, then were remeasured. In each case the readings checked with the previous ones, indicating that the change in filling temperature was permanent; at least within the time of the experiment.

It is apparent, in a general way, that the 110-hour runs have approached closer to equilibrium with the pressure of the external liquid than either of the two shorter runs. Every vacuole heated above the filling temperature, in the manner just described, showed a significant leakage.

Mineral formation temperatures indicated by the liquid inclusion method are, in many cases, much lower than expected from other lines of geologic evidence. This suggests that material may have migrated into the vacuoles after formation. A number of plates were subjected to high water pressures over a period of many hours to test whether water could be forced into the vacuoles.

The filling temperatures of a number of vacuoles were carefully measured. The shape and position of each vacuole were recorded to facilitate quick and accurate location after the pressure test. The plates containing the measured vacuoles were then sealed in a steel bomb, which was heated to 70° C to increase the mobility of the water, but was still well below the filling temperatures. Runs were made at water pressures of 600 and 850 bars. For the 600 bar runs, the pressure was held constant at 600 ± 10 bars for 24 hours. In the case of the 850 bar runs, the pressure was maintained for 60 hours at 850± 10 bars.

The plates were removed from the bomb after the runs and the vacuole filling temperatures were remeasured. The same measuring techniques were employed as previously described. In every case the vacuoles showed a marked drop in the filling temperatures, showing that water had indeed moved into the vacuoles. Typical results are presented in Table 2.

The magnitude of these changes is surprising in view of Grunig's unpublished work on fluorite, reported by Kennedy (6). Grunig's specimen was at least 2 mm thick, and with a two week run under a water pressure of 1,500 bars, the filling temperatures of the vacuoles examined were lowered approximately 10° C. The reason for the apparent discrepancy in the results of Grunig's work and the present study, may lie in the size difference between the quartz plates used in the present study and Grunig's fluorite plate.

The greatest change was shown by the longest runs in both sets of experiments. The vacuoles subjected to the highest external pressures were also those subjected for the longest time. The large change shown by the long runs, as compared to the short runs, may be due to the increased pressure. Vacuoles subjected to high internal pressures showed a larger change in the

TABLE 2.

EFFECT OF EXTERNAL PRESSURE ON THE FILLING TEMPERATURES OF VACUOLES.

Longest diameter of vacuole, mm.	Filling temp. before treatment, °C	Pressure applied, bars	Duration of run, hours	Filling temp. after treatment, °C	Difference between readings before and after treatment, °C
1.25	90	850	60	81	9
1.20	108	850	60	92	16
1.00	109	850	60	94	15
1.00	101	850	60	86	15
0.75	107	850	60	90	17
0.75	97	850	60	81	16
0.75	93	850	60	83	10
0.50	97	850	60	85	12
0.40	101	850	60	87	14
0.25	106	850	60	99	7
1.20	110	600	24	102	8
1.00	111	600	24	106	5
0.75	96	600	24	91	5
0.75	95	600	24	90	5
0.40	108	600	24	102	6
0.30	108	600	24	100	8

long runs than in the short runs. Though equilibrium with the experimental conditions was not reached in any case, it is suggested that with sufficient time the vacuoles may actually come to equilibrium with the imposed experimental conditions.

DISCUSSION.

Many vacuoles in the crystal studied have negative crystal outlines. The belief has been expressed by Buerger (3, p 229) "that most, or perhaps all, of the negative crystals do actually occur on lineage boundaries." Irregular vacuoles, since they behave in the same way as negative crystals, may also occur along lineages. Kennedy (6) has discussed this view and suggested that most primary liquid inclusions in a mineral do actually occur along lineages. He further suggested that fluid could move into and out of the vacuoles along the lineages.

The present study supports Kennedy's suggestion. The results indicate that, whatever the actual path, fluid can migrate into and out of vacuoles in quartz.

Over geologic time, it seems possible that the pressure of the fluid in a vacuole may actually reach or approach equilibrium with surrounding conditions which differ significantly from those at the time of formation.

A suggested case where the vacuoles in a mineral may actually represent later pressure and temperature conditions is that discussed by Dreyer, Garrels and Howland (5). They report on a study of halite crystals from the 900-foot level of the American Salt Co. mine at Lyons, Kansas. The filling temperature of the vacuoles in the salt ranged from 70° to 100° C, suggesting a

minimum temperature of formation for the salt of 70° C. In this reasoning the assumption is made that no material has left the vacuoles since time of formation. It is most improbable that any large body of sea-water depositing halite would ever reach such a temperature. It is even more improbable that the latent heat of crystallization of halite, or an exothermic reaction as suggested by Dreyer et al, could produce a significant rise in temperature. In view of the results of the present study, it is suggested that the indicated temperature was attained during burial of the salt beds subsequent to deposition. Liquid would migrate out at the higher temperature and the apparent temperature of formation would be raised.

The movement of water along lineages is probably by diffusion. It is impossible at present to calculate the rate of this movement. Any temperature or pressure gradient, between the fluid in the vacuole and the fluid surrounding the host mineral, should cause some movement of water along the lineages.

It seems possible, though by no means certain, that the diffusion rate increases as the temperature or pressure gradient increases. Exceedingly long periods may be required for the vacuoles to reach equilibrium under a small pressure gradient. This may explain why liquid inclusions at the present surface of the earth are not in equilibrium with the surrounding conditions.

Formation of secondary liquid inclusions along cracks and flaws, at lower temperatures and pressures than those originally existing during mineral formation, is commonly noticed. Smith et al (9) report quartz veins in the Canadian Shield, whose primary inclusions have a decrepitation temperature of 310° ± 50° C and whose secondary inclusions decrepitate at 140° ± 60° C. The primary inclusions would change under the later conditions, tending towards equilibrium with the new temperature and pressure. The change may be very slow, however, and the time during which the secondary inclusions were formed short by comparsion. This would result in two distinct sets of vacuoles. The primary vacuole would indicate neither the original conditions of formation, nor the conditions operative during the formation of the secondary inclusions.

A wide range of vacuole filling temperatures is frequently noted within a single crystal. If the vacuoles have remained unchanged since time of formation, they should all have the same filling temperature, or show a zonal arrangement corresponding to changing conditions during mineral growth. Similarly, all vacuoles should have the same filling temperature if they were quickly adjusted to ambient temperatures and pressures after formation.

One rarely finds equal filling temperatures or completely consistent zonal arrangements in a mineral. It is suggested that, since the lineage width varies, so does the rate of filling of individual vacuoles. The wider the range of filling temperatures in a single crystal, the less likely it is that the average of the filling temperatures has any definite meaning.

CONCLUSIONS.

The present experiments indicate that considerable care must be taken in using and interpreting temperatures of formations determined from liquid

inclusions. When the evidence from liquid inclusions is at variance with other lines of geologic evidence, as is often the case, it would seem pertinent to consider the possibility that the vacuoles indicate later and different conditions from those operative at the time of formation.

Peach (7) suggested that geologic temperature scales may need revision to be in accord with evidence from the fluid inclusion geothermometer. The writer does not agree with this reasoning, but supports Kennedy's (6, p 547) view "that it is our fundamental assumptions in the use of vacuoles in geologic thermometry that need revision."

ACKNOWLEDGMENTS.

The writer is indebted to the Department of Mineralogy of Harvard University for supplying the quartz crystal used in the study. Professor Kennedy of Harvard originally suggested the need for the work and offered invaluable assistance and criticism throughout the project.

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May 17, 1953.

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RADIOACTIVITY OF RIVERS AND LAKES IN PARTS OF GARLAND AND HOT SPRING COUNTIES, ARKANSAS.

ROBERT H. ARNDT AND PAUL K. KURODA.

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ABSTRACT.

A wide range of radon content in surface waters was noted incidental to studies of radon in spring and well waters of Hot Springs and Potash Sulphur Springs, Garland County, Arkansas. Subsequently a reconnaissance survey of radioactivity of nearby streams and lakes showed the radon contents of streams range from 0.0084 to 1.07 millimicrocuries per liter of water, and those of lakes range from less than 0.001 to 0.123 millimicrocuries. Streams flowing over Ordovician black shales contained an average of 0.275 millimicrocurie radon per liter of water. Those flowing over black Stanley shale of Mississippian age contained an average of 0.046 millimicrocurie radon per liter of water.

The radon content in Potash Sulphur Creek where it flows over the uranium-bearing rocks of the Potash Sulphur Springs syenite complex ranged from 0.09 to 3.16 millimicrocuries per liter of water. Ground water in a drill hole in uranium-bearing rock contained an average of 58.75 millimicrocuries per liter of water. Waters from small springs were shown to lose as much as 41.3 percent of total radon content in the first 4 feet of surface flow below the point of emergence. The methods of radon deter-

mination in the field are believed applicable to prospecting for low-grade uraniferous deposits, especially in black shale areas, in areas of heavy overburden, and in areas of saturation by ground water where ordinary detection devices may be somewhat limited.

INTRODUCTION.

In the area between Hot Springs National Park, in east-central Garland County, and Malvern, some 16 miles to the southeast in north-central Hot Spring County, Arkansas, there are abundant hot and cold springs, streams, and lakes that contain more than an average amount of radon. Interest in radioactivity of waters of this area first centered on the hot springs of Hot Springs National Park. Their radioactivity was first measured in 1905 by Boltwood (1),[1] and has been restudied subsequently by several investigators. The most recent series of studies are by Kuroda, Damon, and Hyde (6).

Six miles southeast of Hot Springs are the mineral springs at Potash Sulphur Springs, associated with an intrusive complex of radioactive syenite and uranium-bearing rock. Five miles farther east are the highly-mineralized intrusive syenites of the Magnet Cove area. At Magnet Cove, radioactive rocks associated with rutile deposits and with tufa are principally thorium-bearing.

Many large and small streams drain the area. Some have their courses entirely within sedimentary rock; a few are entirely within the boundaries of one formation. Others cross igneous areas close to uranium- and thorium-bearing rocks. Observations at Potash Sulphur Springs revealed unusually high radon concentrations in the ground water from uranium-bearing rock and in adjacent springs and creeks.

A review of literature suggested that there is a paucity of published data concerning the areal distribution of radon in surface waters that flow near or through uranium-bearing rocks. The geologic conditions of this area are ideally suited for a regional study of such a nature; therefore, the present limited reconnaissance survey was undertaken in behalf of the United States Atomic Energy Commission. Methods, results, interpretation, and implications are discussed in the following paragraphs.

EXPERIMENTAL DATA.

Apparatus.—An I.M.-type fontactoscope (7) was used throughout this study. A larger ionization chamber ($V = 11.25$ liters), instead of the regular size ($V = 5$ liters), was used for the determination of radon at the smaller concentrations in water. Portable Geiger counters could not be used, because of their low sensitivity.

Field Determination of 10^{-9} to 10^{-11} Curie per Liter of Radon in Natural Water. (Method A).—The lower limit of sensitivity of the I.M. fontactoscope is about 1 to 2×10^{-11} curie radon per liter of water, when a 500 ml water sample is measured in the regular ($V = 5$ liters) ionization chamber. Samples that contained considerably more than 10^{-9} curie radon per liter were diluted with radon-free water. The sample water was shaken in the ionization

[1] Numbers in parentheses refer to Bibliography at end of paper.

chamber, and radioactivity of the air in the ionization chamber was measured at intervals over a period of 30 minutes following the shaking procedure. The radon content of the sample water is calculated as follows:

$$Q = KI_0\left(1 + \frac{\alpha_t v}{V - v}\right)\frac{1000}{v}, \qquad (1)$$

where K = the sensitivity constant of the instrument,
I_0 = the initial radioactivity from radon,
α_t = the partition coefficient of radon at temperature t,
v = the volume of sample water,
V = the volume of the ionization chamber.

The sensitivity constant (K) of the instrument was obtained by means of the radon standard of the Institute of Scientific Research, Tokyo, Japan, and the radium standard solutions of the United States Bureau of Standards. The agreement between the two values was satisfactory.

$K_1 = 0.14_2 \times 10^{-9}$ curie per division per minute, calibrated against the Japanese standard, (2)

$K_2 = 0.14_6 \times 10^{-9}$ curie per division per minute, calibrated against the U. S. standard. (3)

Field Determination of 10^{-11} to 10^{-12} Curie per Liter of Radon in Natural Water. (*Method B*).—The larger ionization chamber ($V = 11.25$ liters) and a larger amount of sample water ($v = 3.9$ liters) were used for the determination of the lower concentrations of radon in natural waters. The lower limit of sensitivity of the method was found to be about 2×10^{-12} curie radon per liter. Approximately 100 times as much ionization current as the background readings was observed with a sample containing 3.6×10^{-10} curie radon per liter.

TABLE 1.

MODEL EXPERIMENTS TO DETERMINE ACCURACY OF FONTACTOSCOPE MEASUREMENTS.

Experiment number	Radon present	Radon added	Radon total	Radon found	Error (percent)	Ionization chamber $V =$
	(10^{-9} curie per liter)					
(1)	0.0023	0.0027	0.0050	0.0052	+4.0	11.25 l.
(2)	0.0023	0.0055	0.0078	0.0076	−2.6	11.25 l.
(3)	0.0023	0.0082	0.0105	0.0099	−5.7	11.25 l.
(4)	0.0023	0.0110	0.0133	0.0128	+3.8	11.25 l.
(5)	0.0023	0.0137	0.0160	0.0164	+2.5	11.25 l.
(6)	0.0023	0.0164	0.0187	0.0193	+3.2	11.25 l.
(7)	0.0023	0.0192	0.0215	0.0214	−0.5	11.25 l.
(8)	0.000	0.212	0.212	0.216	+1.9	5 l.
(9)	0.000	0.330	0.330	0.340	+3.0	5 l.
(10)	0.000	1.060	1.060	1.040	−1.9	5 l.
(11)	0.000	1.272	1.272	1.308	+2.8	5 l.
(12)	0.000	2.650	2.650	2.580	−2.6	5 l.

Table 1 presents the results of a set of model experiments, in which known amounts of radon were added to the water, and the measurements were made with the large and small ionization chambers. It is clear that the method is sufficiently accurate for the present purpose.

Evaporation Method for the Determination of More than 10^{-8} Curie Radon per Liter of Water.—For the determination of radon in natural waters at concentrations higher than 10^{-8} curie per liter, a simple evaporation method was used. The water sample (1 to 2 ml) was evaporated quickly to dryness in a small dish, and the radioactivity of the short-lived decay products of radon in the dish was measured with a Lauritsen electroscope. The instrument was calibrated against the standard radon solutions prepared with the radium standard solution obtained from the United States Bureau of Standards. 1 ml of the radium standard solution (1.00×10^{-9} gram Ra per ml), which was kept in a sealed bottle for one month and which, therefore, had obtained equilibrium between radium and radon, was evaporated to dryness in a small dish, and the alpha radioactivity was measured over a period of a few hours. The radioactivity decreased gradually for the first three hours (radioactivity from the short-lived decay products of radon, I_S) and finally reached the constant value (radioactivity from radium and the long-lived decay products of radon, I_L).

In the case of mineral waters, in which there generally is a large excess of radon to radium and to the long-lived decay products, the radioactivity approached zero after approximately three hours. The sensitivity constants of the instrument, K_{10} and K_{20}, were obtained from the values of I_S 10 minutes and 20 minutes, respectively, after the evaporation procedure.

$$K_{10} = 0.11_5 \times 10^{-9} \text{ curie Rn per division per minute,} \qquad (4)$$

$$K_{20} = 0.13_8 \times 10^{-9} \text{ curie Rn per division per minute.} \qquad (5)$$

The observed radioactivity, when 1 ml of radium standard solution (1.00×10^{-9} gram Ra per ml), in which there is equilibrium between radium and radon, was evaporated to dryness and the radioactivity was measured with a Lauritsen electroscope through a 0.003-mm aluminum foil window, is shown in Table 2.

The radon contents of several radon solutions were determined by the evaporation method and by the fontactoscope method. The agreements between the values obtained by the two methods were satisfactory, as shown in Table 3.

The evaporation method is less accurate than the fontactoscope method, as it is difficult to evaporate more than a few ml of sample water within a short time. Hence the method is limited to the samples containing more than 10^{-8} curie radon per liter. When the salt concentration of the water is high, the effect of absorption should be taken into consideration.

RADON CONTENT OF NATURAL WATERS.

The radon contents of flowing creek waters in this area range from 0.0084×10^{-9} curie per liter to 1.07×10^{-9} curie per liter, exclusive of a branch of

TABLE 2.

RADIOACTIVITY MEASUREMENTS BY THE EVAPORATION METHOD.

Time after evaporation (minutes)	Observed radioactivity, $I_{obs.}$	Radioactivity from radium and long-lived decay products, I_L	Radioactivity from short-lived decay products, I_S
	(divisions per minute)		
5	13.1	—	9.4
10	12.4	—	8.7
20	11.2	—	7.5
30	10.6	—	6.9
40	9.7	—	6.0
50	9.2	—	5.5
60	7.8	—	4.1
70	6.9	—	3.2
80	6.4	—	2.7
90	5.5	—	1.8
100	5.8	—	2.1
120	4.2	—	0.5
150	4.1	—	0.4
200	3.7	3.7	—
260	3.7	3.7	—

Potash Sulphur Creek in which was found a radon content of 17.6×10^{-9} curie per liter. Contrastingly, radon contents of impounded waters of creeks and in Lake Hamilton and Lake Catherine range from less than 0.001×10^{-9} curie per liter to 0.035×10^{-9} curie per liter.

Table 4 presents contrasting determinations of radon in natural waters of China, Manchuria, and Japan, and illustrates the inadequate nature of available information.

Factors which Influence Radon Contents of Streams.—Several creeks were found to have generally higher radon contents in their headwaters than in their lower courses. Hot Springs Creek, Gulpha Creek, and Cove Creek (Fig. 1) are notable examples. It is thought that loss of radon in turbulently-flowing waters, dilution by increase of the size of the stream without proportionate addition of radon, and the rapid decay of radon, as well as the factors of solubility of radon in water as affected by temperature and pressure, may combine to produce such effects.

In the headwaters of Middle Branch of Gulpha Creek the radon content increased for a short distance in a downstream direction. It is possible that the radon content of ground water feeding the stream becomes somewhat

TABLE 3.

AGREEMENT BETWEEN THE EVAPORATION METHOD AND THE FONTACTOSCOPE METHOD.
(Unit: 10^{-9} curie/l.)

Method	Radon standard	(1)	(2)	(3)	(4)	(5)
Evaporation	U. S. A.	46	56	54	53	46
Fontactoscope	Japan	46.9	54.2	54.5	54.4	43.1

higher downstream. If so, it might be expected that a proportionally-large addition to a stream at any one point (of ground water with relatively high radon content) may be perceptible in the total radon content of the stream water at or below the point of its influx. It is also possible that the loss of radon in rapidly- and turbulently-flowing headwaters of a stream may be more rapid than at some distance downstream where the volume and depth of the stream are greater, and the ratio of the surface of the stream to the total volume is smaller than in the headwaters. Such conditions might cause a local increase in total radon content in a downstream direction. Therefore, the gradient of a stream, the nature of its bed, and the character of its flow may affect seriously the radon content of the water.

It is necessary also to consider the geological environment of the whole or parts of the stream and the influence of rock type on radon content, for the radioactivity of individual formations and lithologic types of rock can vary widely. Black shale is generally the most radioactive of common sedimentary

TABLE 4.

RADON CONTENTS OF FOREIGN WELLS AND RIVERS.

Locality	Number of samples	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content 10^{-9}c/l.
Wells in Manchuria and China (4) (8)	41			0.84
Rivers in Manchuria and China (4) (8)	4			0.04
Tatara River, Kyushu Island, Japan (3)		0.0059	0.0032	
Ishido River, Kyushu Island, Japan (3)		0.0066 (ebb tide)	0.0013 (high tide)	

rocks, whereas ordinary sandstone generally contains very little radioactive material. The radon content of ground water derived from an individual formation or one type of rock can be expected to reflect the radioactivity of that rock and, thus, that of the streams to which it has access, providing there is no appreciable influx of radon-bearing juvenile water into a given formation.

GEOLOGY.

Stratigraphy.—The area around Hot Springs and Magnet Cove is underlain by sedimentary rock of age ranging from Ordovician to Mississippian. The sedimentary rocks belong to two lithologic groups: gray or black shale, and siliceous types such as sandstone and novaculite. Syenetic and lamprophyric rocks penetrate the sedimentary rocks locally as dikes, and at Potash Sulphur Springs and Magnet Cove, east of Hot Springs, as stocklike complexes of syenitic rock.

Ordovician rocks are principally black shale with thin, interbedded sandstone and limestone layers. Mazarn shale, the oldest formation exposed in the area, is a black and green shale formation some 1,000 feet in thickness. It is overlain unconformably in some places by the Blakely sandstone approximately 500 feet in thickness, or where that is absent, by the next higher forma-

tion, Womble shale. Womble shale is largely black shale that ranges from 250 to 900 feet in thickness. Seven hundred feet of Bigfort chert, actually interbedded chert and black shale, lie above the Womble shale and are in turn overlain conformably by 25 to 200 feet of black Polk Creek shale.

Blaylock sandstone and Missouri Mountain shale are of Silurian age. Blaylock sandstone is exposed only south of the Ouachita River (10). It probably lies disconformably on Polk Creek Shale and is overlain by Missouri Mountain shale. The formation is sandstone with minor amounts of dark shale and ranges from 0 to 550 feet thick. Missouri Mountain shale is buff to olive green shale, some 50 to 100 feet thick.

Arkansas novaculite lies disconformably on Missouri Mountain shale. The novaculite ideally consists of lower and upper chert-like members separated by

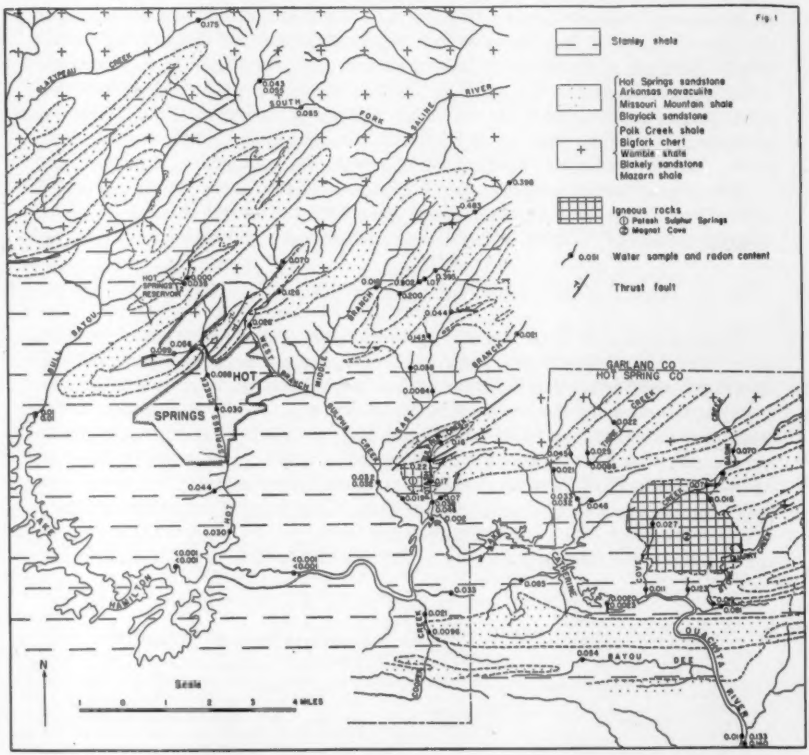

FIG. 1. Generalized geologic map of parts of Garland and Hot Spring counties, showing radon contents of surface waters. Radon contents expressed as 10^{-9} curie/liter of water. (Geology after Arndt, Purdue and Miser (10), and Parks (9).)

a middle gray-to-green shale member. Total thickness may range from 100 to 700 feet. It is of Devonian age except the upper part, which may be of Mississippian age (2).

The Mississippian System is represented by Hot Springs sandstone and Stanley shale. A basal conglomerate separates the Hot Springs sandstone from underlying Arkansas novaculite. The sandstone ranges from 0 to 200 feet in thickness and is absent south of the Ouachita River (10). It grades upward into Stanley shale, which may attain as much as 6,000 feet total thickness. Stanley shale is black-to-dark-green shale interbedded with sandstone.

Structural Geology.—Figure 1 shows the distribution of the formations and the location and measured radon content of samples of stream and lake waters. As the area is located on the southern flank of the Ouachita anticlinorium, the oldest formations are exposed at the north, and other formations in general are progressively younger toward the south. The geology lends itself to simple division of the area into three belts. The northermost division is underlain largely by black shale which includes Mazarn, Blakely, Womble, Bigfork, and Polk Creek formations. The middle division consists largely of siliceous rocks, sandstone, and novaculite, and includes Missouri Mountain shale, Arkansas novaculite, and Hot Springs sandstone. Gray-to-black Stanley shale comprises the southern division, exposed largely in the southern part of the map.

The zigzag pattern of the middle division reflects marked folding of the beds. Fold axes trend northeast and plunge to the southwest. The zigzag outcrop pattern of resistant siliceous beds developed with erosion.

ANALYSIS OF RADON CONTENTS OF STREAMS AND LAKES.

Limited available data concerning the average radon contents of streams where the streams flow through specific formations are summarized in Table 5. The data suggest that the different formations may have individual effects on the radon content of a stream. However, the relatively-high average radon content of samples taken from streams flowing through Bigfork chert may be an exaggeration of true character in that the radon contents of samples obtained in the headwaters of Middle Branch of Gulpha Creek and the headwaters of Mill Creek (Table 6) are much higher than those from three other localities. It is not apparent which set of figures approaches most closely a reliable average radon content for water flowing in Bigfork chert. It is apparent, however,

TABLE 5.

RADON CONTENTS OF STREAM WATERS REFERRED TO BEDROCK FORMATION AT POINTS OF SAMPLING.

Formation	Number of samples	Max. content 10^{-8}c/l.	Min. content 10^{-8}c/l.	Average content 10^{-8}c/l.
Stanley shale	25	0.145	0.0084	0.036
Polk Creek shale	2	0.126	0.070	0.098
Bigfork chert	9	1.07	0.056	0.381
Womble shale	3	0.398	0.043	0.165

TABLE 6.

RADON CONTENT OF STREAM WATERS FLOWING IN BIGFORK CHERT, ARRANGED BY AREAS.

Area	Number of samples	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content 10^{-9}c/l.
Gulpha Creek Middle Branch and Mill Creek	5	1.07	0.20	0.610
Hot Spring Creek, Glazypeau Creek, S. Fork Saline River	4	0.175	0.056	0.094

that Middle Fork and Mill Creek flow in Bigfork chert within the same breached anticline and thus involve areal, stratigraphic, and structural localization of the high radon values.

Table 7 presents radon contents of streams originating and flowing in Stanley shale only, or originating in siliceous rock younger than the Polk Creek shale, and flowing through Stanley shale over most of their courses. Streams rising in any of the older black shales were eliminated from the table, as were values determined from parts of streams below points where they flowed through igneous rock. Except for one point on East Branch of Gulpha Creek and one point on Potash Sulphur Creek above the syenite complex, the order of magnitude of radon content was less than 10^{-10} curie per liter and the general average radon content of the samples used in Table 7 is 0.046×10^{-9} curie per liter.

Data available for water flowing in the Womble shale and Polk Creek shale are too sparse to warrant individual treatment.

Radon Content of Potash Sulphur Creek.—Radon contents of Potash Sulphur Creek and adjacent parts of Lake Catherine are presented in Table 8 and in Figure 2. The minimum value of radon content is of the order of magnitude 10^{-10} curie per liter, in a sample obtained 500 feet above the mouth of the creek. Surrounding bedrock is Stanley shale, in which stream water has been shown previously to contain an amount of radon of a similar order of magnitude. The radon content of the creek at the point at which it flows through Stanley shale,

TABLE 7.

RADON CONTENT OF STREAMS RISING AND FLOWING IN SILICEOUS ROCK AND STANLEY SHALE, ARRANGED BY STREAM SYSTEMS.

Stream system	Number of samples	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content 10^{-9}c/l.
Tigre Creek tributaries	4	0.046	0.021	0.034
Bayou Dee	1			0.054
Gulpha Creek, East Branch	5	0.145	0.021	0.055
Tributary to Hot Springs Creek	1			0.044
Tributary to Cooper Creek	1			0.033
Tributary to Lake Catherine, S. shore	1			0.085
Potash Sulphur Creek	1			0.16
General weighted average				0.046

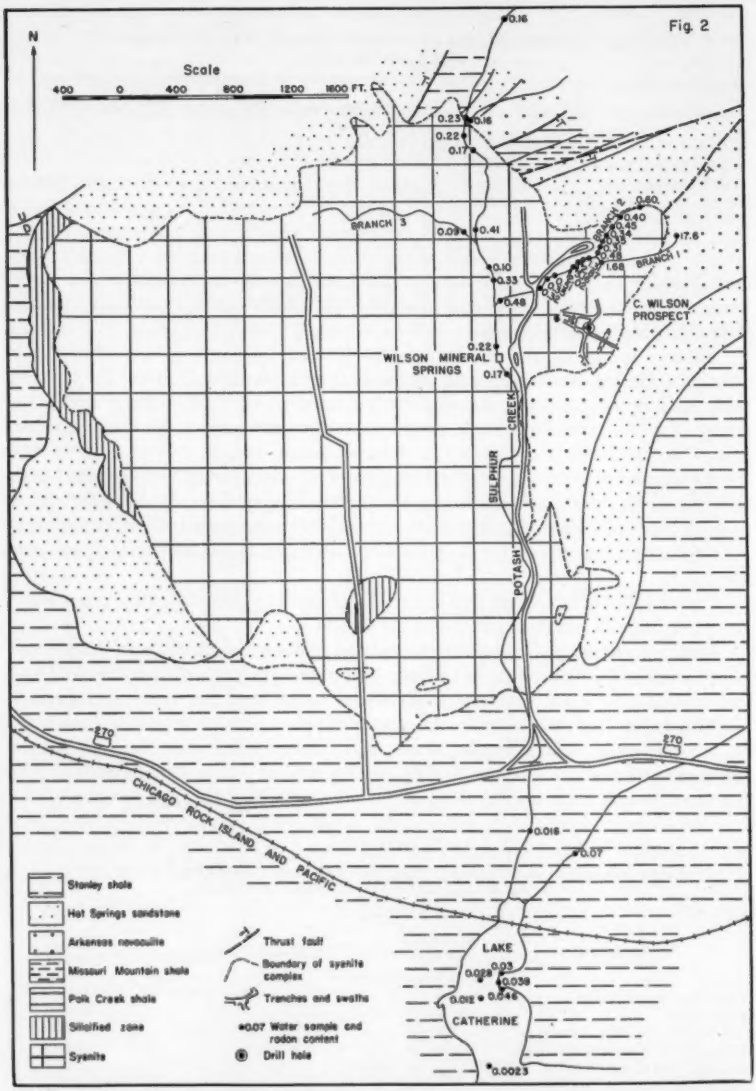

FIG. 2. Generalized geologic map of Potash Sulphur Springs syenite complex and vicinity, showing radon contents of surface waters. Radon contents expressed as 10^{-9} curie/liter of water.

above the igneous complex, is 0.16×10^{-9} curie per liter (Table 8), slightly higher than the average value of streams flowing in this formation. Within the area of the igneous complex, which consists of much altered syenetic and lamprophyric rocks, and between the position of the two samples listed previously, the average radon content of Potash Sulphur Creek ranges from 0.17×10^{-9} curies per liter to 0.225×10^{-9} curie per liter in different segments of the creek.

Maximum radon contents are found in the waters of a small branch creek (labeled 1–2) flowing into Potash Sulphur Creek from the northeast, and situated in a downhill direction from the C. Wilson uranium prospect. Average radon content along this creek is 1.057×10^{-9} curie per liter. Above the confluence of the branch creek with Potash Sulphur Creek the average radon content of Potash Sulphur Creek is 0.225×10^{-9} curie per liter. Two hundred

TABLE 8.

RADON CONTENT OF POTASH SULPHUR CREEK AND LAKE CATHERINE ADJACENT TO THE MOUTH OF POTASH SULPHUR CREEK.

Area sampled	Number of samples	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content
Flowing in Stanley shale north of igneous mass	1			0.16
In igneous area above Branch 1–2	6	0.41	0.09	0.225
Branch 1–2	14	3.16*	0.32	1.057
275 feet below mouth Branch 1–2	1			0.22
Wilson Spring (cased)	2	2.35	1.83	2.09
500 feet below mouth Branch 1–2	1			0.17
500 feet above mouth of P.S. Creek	1			0.06
Bay of L. Catherine, mouth of P.S. Creek	4	0.046	0.012	0.027
Mouth of bay on L. Catherine	1			0.0023

* Excluding one anomalous high reading = 17.6×10^{-9} c/l.

and seventy-five feet below the confluence Potash Sulphur Creek has 0.22×10^{-9} curie per liter water. Water used as commercial mineral water, and drawn from a tap connected to a cased spring in the bed of Potash Sulphur Creek, 375 feet below Branch 1–2, contains an average of 2.09×10^{-9} curie per liter radon. The radon content of Potash Sulphur Creek drops to 0.17×10^{-9} curie per liter 500 feet below Branch 1–2.

The radon contents of springs and seeps adjacent to the C. Wilson uranium prospect are presented in Table 9. Most of the determinations were made from water gathered directly at the orifice of the spring or seep. Samples were taken from the drill hole at 30-minute intervals during the process of bailing the hole by bucket. No perceptible change in the water level resulted from bailing the drill hole continuously, but whether this indicates that the level was maintained by inflow of water, or whether it resulted from wall material caving into the hole, was not determined. Nevertheless, it is obvious from these data that the radon content of the ground water in and adjacent to the prospect far exceeds the radon contents of the streams and creeks.

TABLE 9.

RADON CONTENTS OF SPRING WATERS AND SEEPS ADJACENT TO THE C. WILSON URANIUM PROSPECT, POTASH SULPHUR SPRINGS.

Area	Number of springs	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content 10^{-9}c/l.
Along bank of Branch 1–2, NW. of prospect excavations	6	39.9	6.33	15.88
Slope S. of prospect excavations	4	14.2	8.57	10.64
Wilson Spring (cased) West of prospect: 2 observations		2.35	1.83	2.09
Drill hole in prospect excavations: 10 observations		64.3	42.6	58.75

This was not unexpected, for, as suggested previously, the creek waters lose their radon rapidly where creeks are very small and their flow is turbulent. Table 10 presents the change of radon content of water with increased distance from the orifice of one spring which emerges along the bank of Branch 1–2 of Potash Sulphur Creek.

For several reasons, the total radon content of Potash Sulphur Creek is influenced very little by the inflow of ground water adjacent to the uranium prospect. The radon content of Branch 1–2 has been reduced to 0.48×10^{-9} curie per liter at its mouth from the over-all average of 1.057×10^{-9} curie per liter. As the total flow of Branch 1–2 is small, its radon content is reduced by dilution when it joins Potash Sulphur Creek. Ground water seepage into the bed of Potash Sulphur Creek along a total distance of 1,000 feet below the mouth of Branch 1–2, the area of probable drainage for ground water from the prospect, also must be of small volume in contrast to the total flow of the stream, and the dilution factor probably is large.

Thus, the average radon content of Potash Sulphur Creek where it flows through syenitic rock is greater than that of most other streams flowing in the Hot Springs-Magnet Cove area by a factor of 10. Relatively-high radioactivity in the surrounding rocks is generally reflected in the radon content of the stream. Local changes in radioactivity of bedrock are not usually reflected in the radon content of the streams, except in the very small tributaries to the main creeks. Ground water sampled at the orifices of seeps and springs provides the most striking indications of local changes of radioactivity in the rocks.

TABLE 10.

RADON CONTENT OF A SPRING MEASURED AT THE ORIFICE AND IN THE RESULTANT SURFACE FLOW.

Location in respect to orifice	Radon content 10^{-9}c/l.	Loss of radon (percent)
Orifice	15.4	
1 foot from orifice	14.3	7.2
2 feet from orifice	13.2	14.3
4 feet from orifice	9.05	41.3

Radon Content of Cove Creek.—No appreciable effect of igneous rocks on the radon content of streams has been noted in a few samples taken from the vicinity of such rocks at Magnet Cove. Cove Creek, on the northern border of the syenite complex, and Basin Creek, a tributary, have radon contents of 0.07×10^{-9} curie per liter. Contrastingly, the radon content of Cove Creek within the complex is 0.027×10^{-9} curie per liter, and at its mouth, in Stanley shale, it is 0.011×10^{-9} curie per liter. Thus, in general magnitude, the radon content of Cove Creek flowing through igneous rocks is only about one-tenth that of Potash Sulphur Creek where it flows through igneous rocks. Water in a ponded creek which flows south from near the southern border of the igneous complex has a radon content of 0.123×10^{-9} curie per liter, but the source of the radon is unknown. Although data are sparse, the syenites at Magnet Cove appear to contribute little to the radon content of the streams.

TABLE 11.

RADON CONTENTS OF LAKES AND PONDS.

Area	Number of samples	Max. content 10^{-9}c/l.	Min. content 10^{-9}c/l.	Average content
Lake Catherine, exclusive of large bays	11	0.0023	0.0014*	0.0018
Lake Catherine, Gulpha Creek Bay	1			0.013
Lake Catherine, Potash Sulphur Creek Bay	4	0.046	0.012	0.027
Lake Hamilton	2			less than 0.002
Lake Hamilton, mouth of Bull Bayou	2	0.014	0.010	0.012
Lake Hamilton, mouth of Hot Springs Creek	1			0.030
Hot Springs city reservoirs on Bull Bayou				
Number 1	1			0.000
Number 2	1			0.035
Pond on creek south of Magnet Cove complex	1			0.123

* Does not include several determinations listed as less than 0.002 and less than 0.001.

This agrees with general knowledge that much of the radioactivity observed in rocks at Magnet Cove emanates from thorium rather than from uranium.

Radon Contents of Lakes and Ponds.—These data are summarized in Table 11. Lakes and ponds in the area are comprised of artificially impounded water in stream and river channels. Lake Hamilton and Lake Catherine are dammed parts of the Ouachita River.

It is apparent that the radon concentration in large bodies of water generally is less than $.002 \times 10^{-9}$ curie per liter. Local exceptions occur in bays at the mouths of relatively large tributaries such as Bull Bayou, Hot Springs Creek, Gulpha Creek, and Potash Sulphur Creek, where radon concentration is about $.0X \times 10^{-9}$ curie per liter. This is approximately the order of magnitude of radon concentration of streams flowing in Stanley shale. It is believed that the radon concentration is maintained at a higher level in the water of these bays because the narrow mouths of the bays prevent inflowing stream waters

from mixing rapidly with other lake waters which have low radon concentrations. Table 8 and Figure 1 illustrate the change in radon content of the water at the mouth of Potash Sulphur Creek Bay, where bay waters are diluted by lake water.

Low radon concentrations in the large bodies of water are to be expected, for most of the waters are far from their source in distance and time. The decay rate of radon (3.82 days half life) and the escape of radon as a result of the low solubility of radon in water rapidly reduce the radon content to the low levels observed.

The reason for somewhat anomalous contrasting radon contents of water in the Hot Springs city reservoirs has not been determined. It must be noted that the content in Reservoir No. 2 is essentially that of streams flowing in Stanley shale. Likewise, the high radon content of a small pond on a creek running southward from the southern border of Magnet Cove syenite complex is unexplained. It is possible that the radon content is derived from the igneous rocks of the southern part of the syenite complex where the creek has its headwaters.

DIRECT INFLUENCE OF RADIOACTIVE BEDROCK ON RADON CONTENT OF GROUND WATER.

A gross study of the correlation between the radon contents of streams, creeks, springs, and rock has not been made for want of sufficient information regarding the radioactivity of individual rock types. However, at Potash Sulphur Springs, the amount of uranium in the rocks of the C. Wilson prospect is fairly well known.

At that locality the rock is strongly-brecciated, highly-altered, light-colored syenite. Apparently, porphyritic-feldspar dikes and fine-grained granular dark dikes intrude the syenite along strongly-fractured zones and emphasize the stockwork character of the broken syenite. It is believed that the whole mass was altered subsequently by hydrothermal solutions that introduced uranium, and accompanying niobium, zirconium, titanium, and vanadium, which also are relatively abundant in the rocks. Yellow clay with abundant mica flakes, white clay containing ghosts of feldspar phenocrysts, brown and gray pulverulent rock with residual fine-grained, granular igneous texture, some sticky green clay, and occasional masses of glassy quartz are altered remnants of the original rock.

Gravimetric analyses indicate a maximum of 0.3 percent UO_3 in the most radioactive samples of gray dike rock. Twenty selected samples of relatively-radioactive rock taken from a face 60 feet long were analyzed radiometrically. Equivalent uranium contents ranged from 0.20 percent to 0.006 percent, and averaged 0.0519 percent. Fluorometric analyses (U. S. Atomic Energy Commission Raw Materials Operations Office, Denver, 1952) of rock from vertical channel samples, spaced at 5-foot intervals, along one wall of the 60-foot face, ranged from 0.029 percent uranium to 0.003 percent uranium. It was material of this type in which the exploratory hole listed in Table 9 was drilled. Cuttings from the hole indicated that the pulverulent rock continues downward at

least to 75 feet, the bottom of the hole. Radon content of the water from this hole averaged 58.75×10^{-9} curie per liter. As the water samples were gathered at the top of the water in the hole, 20 feet below the ground level, it is assumed that its radon content is essentially that of the ground water which percolates through the deposit.

CONCLUSIONS.

Regional levels for the radon content of streams flowing in any one formation can be established if the areas of outcrop of individual formations are relatively broad and of regular pattern. The radon content of the water in streams that traverse several formations of relatively narrow outcrop cannot be expected to reflect the radioactivity characteristics of each formation. In such cases, the radon contents of subsequent tributaries that flow in only one formation may represent more truly the radioactive characteristics of stream waters of that formation.

The regional level of radon contents of streams can be expected to be generally much lower than that of the ground water within the area of drainage. Rapid loss of radon in flowing water has been demonstrated by measurements at the orifices of individual radioactive springs and seeps. The gradient of a stream, its velocity, volume, and the nature of its bottom all contribute to the rate of loss of radon. Strong turbulence associated with rapid flow of small volumes of water probably induces the most rapid loss of radon.

It is to be expected that radon contents of large streams and lakes will not be the same as those of tributaries. Much of the water in lakes and large streams is far from its source in distance and time, and as a consequence radon content is reduced by rapid decay. The water in a large stream is the composite from a large drainage area that may be underlain by many different formations of a wide range of radioactive content. The large volume of a master stream in proportion to that of its tributaries effects great dilution of the radon contents of the tributaries, as demonstrated at the mouths of bays on Lake Hamilton and Lake Catherine.

The methods described may be applicable to relatively rapid reconnaissance in prospecting for low-grade uranium deposits. Instruments may be carried into the field in station wagon, panel truck, or Jeep for on-the-spot measurement. Determination of radon content is relatively rapid.

Physical limitations are apparent. There must be sufficient rainfall to provide an abundance of permanent small streams and creeks. Therefore, the applicability of the method to regional reconnaissance in semi-arid land is questionable. As rapid variation of radon content can be expected only in small creeks and streams, the isolation of an area that is a probable source of radon requires analysis of the water from numerous small tributaries. Measurements should be made at times of normal stream flow rather than during flood or times of drought. The equipment is somewhat more delicate and less portable than common surface radioactivity detection apparatus.

The advantages are many. The distribution pattern of unusual quantities of radon in spring and stream waters may aid in isolating the possible source

areas for the radon. It may be especially helpful where direct radiation from the source is shielded from surface detection because of thick overburden or unusual saturation of the source by ground water.

The presence of radon in stream water in areas containing radioactive rocks indicates the proximity of uranium-derived radium and, indirectly, the presence of uranium with or without thorium.

The sensitivity and applicability of the method as a prospecting method for low-grade uranium deposits are suggested by contrasting results of radon surveys with those of surface radioactivity surveys at Potash Sulphur Springs (11). Average surface radioactivity over igneous rocks present in the outer shell of the Potash Sulphur Springs igneous complex is a little more than two times the average radioactivity background measured over the sandstone, quartzite, and chalcedonic rocks that surround the complex. Average background over igneous rock is of approximately the same level as that measured over black Stanley shale adjacent to the complex. However, the average radon content of Potash Sulphur Creek (at the point at which it flows within the confines of the complex) is approximately ten times greater than that of water flowing in Stanley shale. The contrast between average surface radioactivity and average radon content of the water does not represent fully the field relationships, because, locally, background activity over igneous rock rises to five times the average of that over surrounding siliceous rock. However, locally, stream and creek waters in the complex contain radon in excess by order of magnitude of 100 times that of the average stream water that flows in surrounding Stanley shale.

Radon surveys may be means of relatively-rapid reconnaissance preliminary to detailed grid surface surveys.

Broad regional levels of the radon contents of stream waters relative to individual formations or to lithologic types cannot be defined by this study because data are sparse. Further study in that direction is desirable. It is recognized likewise that the technique has been applied only in a relatively-small area which may contain geologic conditions peculiarly suited to radon surveys. Closer correlation between the radon contents of streams and of ground water and its application to uranium prospecting are necessary. Further investigation is contemplated.

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SIGNIFICANCE OF PLEISTOCENE DEPOSITS IN THE GROUNDWATER RESOURCES OF ILLINOIS.

JOHN W. FOSTER.

ABSTRACT.

Among the developed and potential sources of large public and industrial groundwater supplies in Illinois, the sand and gravel beds of the Pleistocene rank first. These deposits yield most of the groundwater, yield the greatest quantities of water to specific wells, and contain the largest part of the State's undeveloped resources of low-cost groundwater.

Groundwater is one of the vital geologic resources of Illinois. Studies by the Illinois State Geological Survey show that about 55 per cent of the State is underlain by one or more aquifers of industrial importance. Twenty-five of Illinois' twenty-six great industrial cities lie in or near those areas of the State where geology is favorable for groundwater development. Seven of the major industrial cities and at least one hundred other communities depend entirely upon Pleistocene sand and gravel beds for groundwater supplies. Wells of highest water yield (2500–3000 G.P.M.) are constructed in valley-train type sand and gravel deposits which are in many places buried by till. The detection and mapping of these deposits involve integration of geologic and geophysical methods of exploration. These sources of groundwater will be of increasing economic significance where industry can move to the undeveloped areas in which low-cost groundwater can be found in abundance.

BEST known among the sources of large supplies of groundwater in Illinois are the deep sandstones of the northern part of the state. Like the Dakota sandstone of the Northern Plains, the St. Peter and Galesville formations of southern Wisconsin and northern Illinois became famous for their strong artesian pressures. Nevertheless, important as the deep aquifers are in the economy of Illinois, there are better and less costly water supplies of great magnitude in glacial deposits of Pleistocene age.

For years, and to some extent even today, drillers and engineers have gone to great effort in places to case off water-yielding surficial sand and gravel while drilling wells hundreds of feet deep in the solid rock. There are several reasons for this mistake. Most important is the fact that the deep sandstones and even the creviced dolomites are almost certain to be a suitable source of water at any given location in the northern region, while surficial sand and gravel is not often a certainty in advance of drilling. Therefore, most well specifications for industrial or municipal water programs in northern Illinois called for deep well construction without regard to the possibility of finding a good source of groundwater in glacial drift. Furthermore, the phrase "deep artesian" suggests to many the ultimate in water sources, and it was not until recently that the value of shallow Pleistocene sand and gravel beds as water sources became widely recognized in Illinois. Even now the water resources

of the Pleistocene beds are not fully appreciated by all water engineers in the state.

The concentration on the deep sources of water and the neglect of shallow possibilities have led to a number of unfortunate conditions. 1) Pumping costs are sometimes unnecessarily high because of low water levels in deep wells. 2) The cost of well construction may be unnecessarily high, although the actual difference in total cost between a deep rock well and a shallow gravel well may not be large, particularly if it is necessary to locate gravel wells at some distance from place of water use. 3) Industries owning their own deep wells or tapping municipal supply furnished by deep wells use water which is as much as twenty degrees warmer than the available sand-and-gravel water. 4) Failure to make use of shallow Pleistocene sources of water and insistence on drilling to deep aquifers results in lowering the artesian head in adjacent areas where there is no alternative to deep drilling.

The most concentrated exploration for water-yielding sand and gravel deposits of major size has been carried on in the central part of Illinois south of the region where bedrock formations are used as sources of water. Throughout most of central, eastern, and much of southern Illinois there are no usable water supplies in bedrock formations below the glacial drift. It is quite natural, then, that in these areas the water resources of the Pleistocene were developed and investigated early. The discovery of major sources of groundwater where the bedrock contains no fresh groundwater has made certain parts of these regions very attractive to industry. It is understandable that industry for many years has located in northern areas where bedrock groundwater supplies are certain, rather than in areas where the glacial drift may be reputedly a less certain source.

The greatest deterrent to the utilization of water resources in glacial drift has been the fact that it has been impossible to predict the occurrence of buried sand and gravel aquifers. This inability in the past has led to a retarded development of industry in areas where there are no important bedrock aquifers. Mapping the areas where glacial drift is likely to contain good water-yielding deposits is a responsibility of geologists. For many years the State Geological Survey has studied the glacial drift of Illinois by mapping and subsurface study, using thousands of sets of samples furnished by private drilling contractors obtained in their normal course of operations. The Geological Survey now has much information about the buried topography of the bedrock surface and the make-up of the various sheets of drift that were spread by repeated invasions of glaciers. Geophysical methods, particularly electrical earth resistivity from the ground surface, aid materially in the detection of buried sand and gravel beds. As a result of continuous study and a growing library of basic data it is possible to show the specific areas in Illinois where testing for groundwater in glacial drift is likely to be successful. Conversely, it is also possible to predict some places where even moderate supplies of groundwater are scarce and difficult to find.

An example of the usefulness of this kind of geologic work is in the service given industrial engineers of railroads operating in Illinois. The State Geological Survey has furnished geological data on areas served by rail lines that

have unusually favorable conditions for industrial water wells in glacial drift, some of which are completely undeveloped. The railroads can attract industry to those places that have the additional inducement of abundant low-cost groundwater.

The stippled and diagonal patterns on Figure 1 show those areas in Illinois where there is good possibility of constructing wells capable of yielding small to large industrial supplies of water from at least one of the various geologic formations—glacial drift, valley alluvium, or bedrock. The figure also shows large areas in south-central and southern Illinois, amounting to 45 percent of the state, where there are no formations of wide extent suitable for industrial or municipal groundwater, although local ones exist. This part of Illinois is largely covered by the Illinoian glacial drift, which is generally thinner than seventy-five feet and beneath which the bedrock strata are mostly impervious Pennsylvanian shales. Large water-yielding sand and gravel beds are scarce in the Illinoian glacial drift and most of those permeable Pennsylvanian sandstones that do occur yield water of unsatisfactory quality.

Black dots indicate the twenty-six industrial cities in Illinois, which produce annually at least ten million dollars in manufactured goods. Twenty-five out of the twenty-six industrial cities lie in or within access to the groundwater areas! This is not a coincidence. Springfield is the only major industrial city without access to very promising water-yielding formations. Springfield's water supply is an artificial lake.

A distinction is made in Figure 1 between bedrock sources of water and Pleistocene sources. The diagonal pattern indicates bedrock sources; the stippled pattern indicates areas where there is good possibility of water-yielding sand and gravel beds in glacial drift or alluvium. Seven of Illinois' large manufacturing centers lie outside the area of bedrock water and depend on sand and gravel deposits for groundwater.

The south boundary of the diagonal pattern, showing bedrock sources, is determined primarily by the quality of the water. Regionally, the bedrock formations of the north dip gently southward toward the Illinois basin. The salinity of water in the deep sandstone aquifers increases southward to the line of tolerance. Far to the south, the salinity of the groundwater in the St. Peter sandstone, for example, increases to more than 150,000 parts per million.

Note that trains of sand and gravel occupy the present Mississippi and Wabash valleys on the western and eastern margins of Illinois. They are especially significant because they are for the most part in regions where large groundwater supplies can neither be obtained from the bedrock nor from the glacial drift on the uplands.

Figure 2 shows two water wells in the same area that were drilled for the same purpose. Both are public water sources for the city of Rockford. Rockford's location is shown on the index map on the lower left. The city lies in an area where abundant water is available from both deep sandstones and glacial drift. Note the overlap of the patterns near Rockford, Figure 1. Prior to 1947 all of Rockford's water wells tapped the deep sandstones, particularly the Galesville and Mt. Simon formations, at depths to 1,500 feet. Well No. 10, Figure 2, is a typical deep well. Since 1947 a number of sand and gravel

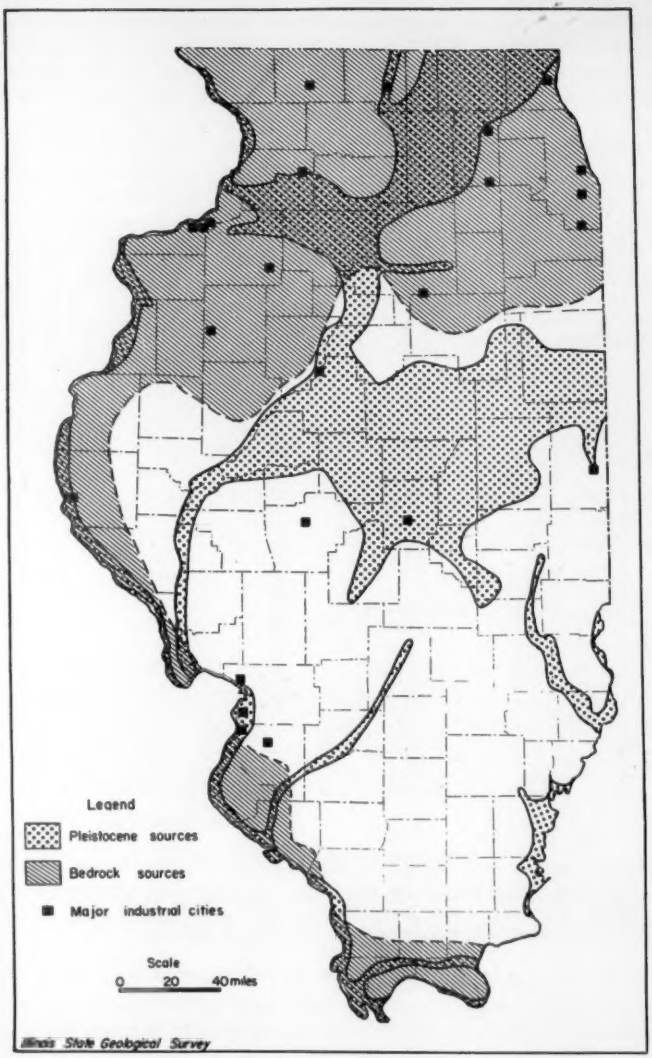

FIG. 1. Shows areas in Illinois where geologic studies indicate good possibility of obtaining small to large industrial supplies of groundwater. Also shown are the major industrial cities and their relation to groundwater areas.

wells about 200 feet deep have been constructed to furnish water to Rockford. Well No. 7A, Figure 2, is a typical shallow well, constructed in valley-train deposits in the ancient Rock River valley. A typical deep well at Rockford, according to State Water Survey data, yields 2,000 gallons per minute from a pumping water level of not less than 300 feet. And, according to State Water

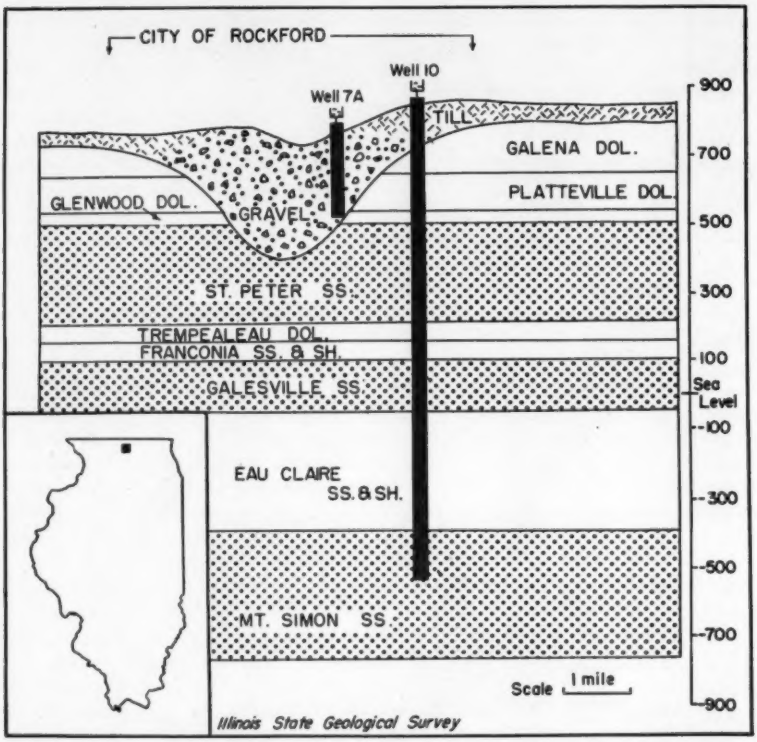

FIG. 2. Cross section showing two wells supplying water to the city of Rockford, Illinois, one a deep bedrock well and the other a shallow screened well in sand and gravel. Comparative performances are given in the text.

Survey data, a typical sand and gravel well at Rockford yields 3,000 gallons per minute from a pumping water level of 65 feet. Near Chicago, many pumping water levels in deep sandstone wells are reported to be below 500 feet.

Some of the most attractive glacial deposits are sands and gravels in the deeply buried preglacial valleys. The glacial deposits here are as thick as 600 feet and the sands and gravels as much as 350 feet. These ancient valleys are either partly or completely buried and obscured. One such major bedrock

valley is the Mahomet (Lower Teays) valley. It enters eastern Illinois from Indiana and continues westerly to the ancient Mississippi valley below Peoria, about ninety miles east of the present Mississippi valley. The Mahomet valley is completely obscured by glacial drift throughout its length in Illinois. The water resources of the sand and gravel beds along this valley are enormous. Their exploitation has just begun.

However, many other good sand and gravel beds in the glacial drift bear no relation to old bedrock valleys. It is most difficult to detect this type of aquifer. Surface electrical earth resistivity investigation is valuable in the discovery of water-yielding beds that are confined within glacial till. Many of these deposits, long in use as sources of water, would not yet have been discovered by random test drilling.

The deep sources of groundwater in Illinois will continue to be very important. The shallow sources, however, will be of increasing economic significance to industry seeking to settle where low-cost groundwater can be found in abundance.

Acknowledgment.—The author is indebted to Dr. Frank C. Foley, Head, Groundwater Division, and to Dr. M. M. Leighton, Chief, Illinois State Geological Survey, for guidance in the preparation of this manuscript. Special acknowledgment is also given Dr. Leighton and others whose work on the Pleistocene geology of Illinois has made these groundwater interpretations possible.

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May 8, 1953.

SOURCES OF ERROR IN THE MEASUREMENT OF ROTATION PROPERTIES WITH THE ORE MICROSCOPE.

EUGENE N. CAMERON, RICHARD W. HUTCHINSON, AND LEWIS H. GREEN.

ABSTRACT.

This paper presents the results of investigation of the optical system of the ore microscope with the purpose of evaluating various sources of error in measurements of rotation properties. The following sources of error are considered: the polarizer, the reflecting plate, the objective, the polished surface itself, and the analyzer. Errors from these sources are found to be due largely to incorrect adjustment of the microscope. Strain in objectives, however, can be a source of serious errors, and the use of strained objectives is undesirable. The reflecting plate introduces errors in angles of rotation and apparent rotation. Measured values must be corrected to true values by reference to a curve constructed for the particular microscope used.

INTRODUCTION.

INVESTIGATIONS of the rotation properties of minerals in reflected light in the Laboratory of Economic Geology at the University of Wisconsin were begun in 1950. With progress of the work, it has become evident that there are a number of possible sources of error in measurement of the properties with available microscopic equipment. The majority of these sources were given qualitative consideration during the work described by Cameron and Green (3).[1] Quantitative data have been needed, however, and a series of studies has therefore been undertaken during the past year and one half. The studies have actually had two purposes: (1) to determine which sources of error are significant and which are not, and (2) to account for certain anomalous color effects noted in polarization figures.

GENERAL CONSIDERATIONS.

Under ideal conditions, light coming from the polarizer to the coated reflecting plate of the microscope is reflected downward without change in azimuth of vibration[2] and passes thence toward the surface of the mineral. If the mineral is anisotropic and transparent and is not at a position of extinction, the vibration plane of the incident light is rotated upon reflection. If the polarizer and analyzer are crossed, the grain appears illuminated. If the analyzer is now rotated, the angular rotation necessary to produce extinction is a measure of the rotation produced by the mineral. If the mineral is

[1] Numbers in parentheses refer to Bibliography at end of paper.

[2] By azimuth of vibration is meant the angle between the plane of vibration of the incident light and the plane of incidence on the surface of the reflecting plate.

absorbing, a phase difference is also introduced upon reflection, and an elliptical vibration results. In this case, the angle measured by rotating the analyzer is the angle between the major axis of the ellipse of vibration and the plane of vibration of the incident light. This angle is the angle of apparent rotation (3, p. 737).

In practice, conditions often are not ideal, and there are various points in the optical system at which errors may be introduced such that (1) the angle measured by the analyzer is not the true angle of rotation or of apparent rotation, or (2) anomalous dispersion effects are produced. In the order of their occurrence along the path of light from the polarizer to the polished surface and thence to the eye, these sources of error are located as follows:

1. In the polarizer, due to incorrect orientation.
2. In the reflecting plate, during reflection of the light downward to the polished surface.
3. In the objectives, during passage of the rays either to or from the polished surface.
4. At the polished surface, owing to tilt of the surface.
5. At the polished surface, owing to ellipticity of the reflected vibration.
6. In the reflecting plate, during passage of the rays upward to the analyzer.
7. In the analyzer.

ERRORS DUE TO INCORRECT ORIENTATION OF THE POLARIZER.

In the following discussion, the plane normal to the rotation axis of the reflecting plate of the microscope is referred to as the plane of incidence of the plate. If the paths of the linear polarized rays coming from the polarizer lie in planes parallel to the plane of incidence of the plate, and if the vibration direction of the polarizer is perpendicular or parallel to the plane of incidence, the rays are reflected downward toward the objective without change in direction of vibration. In the objective, the vibration directions of all rays except the axial ray are rotated by convergence. The azimuths of the rays striking the field of view therefore vary over a considerable range, but under the conditions described above, the azimuths of the reflected vibrations for all wavelengths vary systematically outward from the center of the field and symmetrically with respect to the trace of the vibration plane of the analyzer (Fig. 1), if the analyzer and polarizer are crossed.[3] Under conoscopic conditions, a symmetrical polarization figure is produced. However, if the plane of the polarizer deviates from the perpendicular or parallel, the illumination of the field is no longer symmetrical. The rotation produced by the reflecting plate varies with the wavelength of light, hence there is no one position of the analyzer at which all wavelengths are extinguished in the center of the field and along the diameters of the field parallel and perpendicular to the vibration

[3] In the above discussion, the effects of convergence of the bundle of rays passing from polarizer to reflecting plate (see Berek, 1937, pp. 10–17, and Foster, L. V., 1938) are ignored. Tests with Bausch and Lomb and Spencer microscopes indicate that rotations due to this convergence do not enter significantly into the phenomena observed.

direction of the analyzer. The polarization cross for red light will not be formed at the same position of the analyzer as the polarization cross for blue light. Similarly, if the analyzer is set so as to produce the polarization cross for red light, in the quadrants of the field the vibration directions for blue light are not symmetrically disposed with respect to the diameters of the field parallel and perpendicular to the analyzer. The relationships involved are shown diagrammatically in Figure 2.

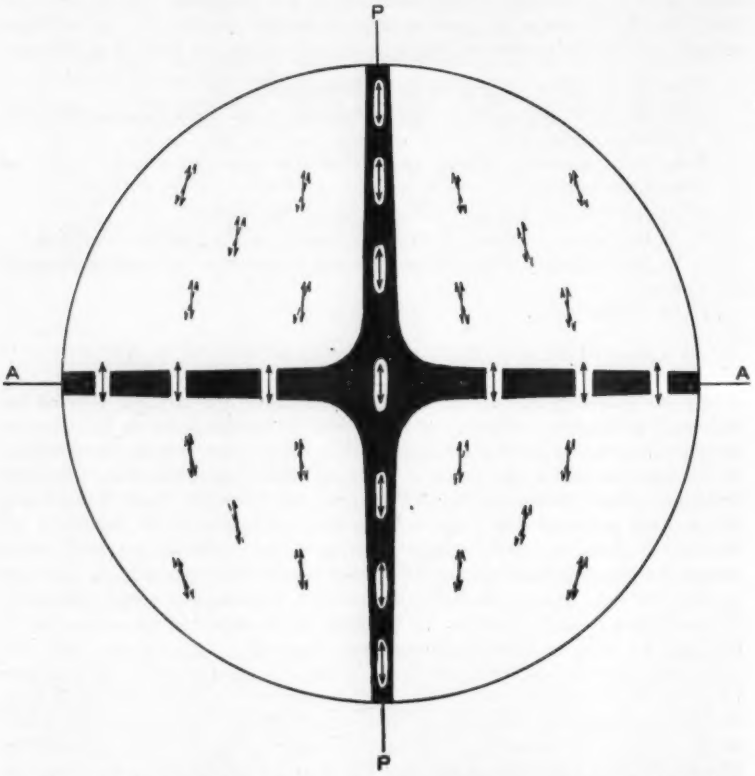

FIG. 1. Pattern of vibration directions for reflected rays of red and blue light, and position of polarization cross, under ideal conoscopic conditions. P-P, projected trace of plane of vibration of polarizer; A-A, projected trace of vibration plane of analyzer. Plane of incidence of reflecting plate is parallel to A-A. Solid barbed lines give vibration directions for rays of red light reflected from various points in the four quadrants; dashed barbed lines give vibration directions of reflected blue rays. Vibration directions along N-S and E-W diameters of field are the same for red as for blue (doubleheaded arrows).

The question is: To what extent are observations of rotation properties affected by incorrect orientation of the polarizer? To answer this question, it is necessary to consider both the angle of apparent rotation and the color fringes due to dispersion. In measuring an angle of rotation or apparent

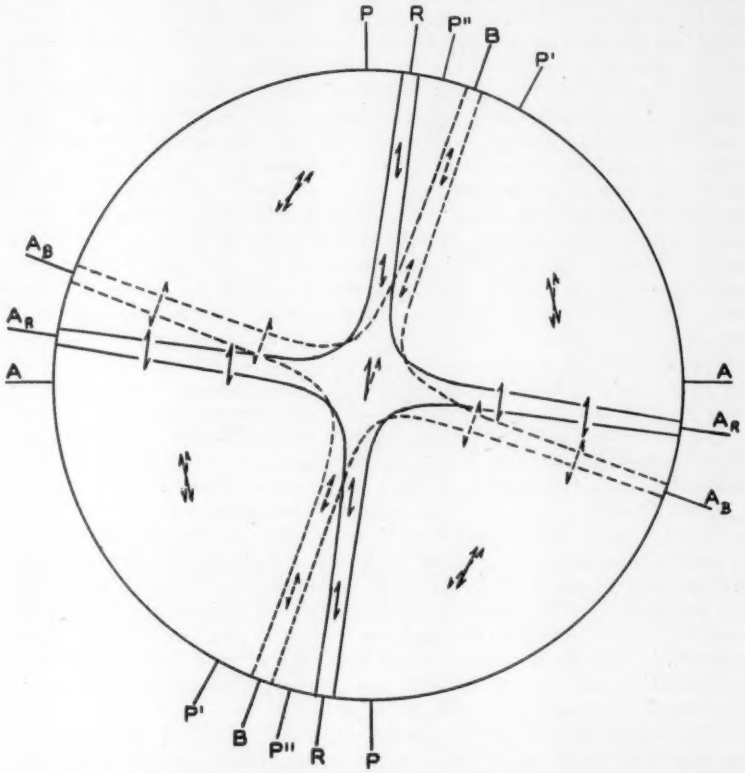

FIG. 2. Diagram to show effects of incorrect orientation of polarizer. Polarizer has been rotated clockwise from P-P to P'-P'. B-B, vibration direction of rays of blue light passing downward to the objective, after rotation by reflection at the lower surface of the reflecting plate; R-R, vibration direction of rays of red light after rotation; P''-P'', mean vibration direction of rays of intermediate wavelength after rotation. Solid short barbed lines give vibration directions for rays of red light reflected from an isotropic mineral; dashed short barbed lines give vibration directions of reflected rays of blue light. A-A, crossed position of analyzer prior to rotation of polarizer; A_R-A_R, crossed position of analyzer for red light after rotation of polarizer; A_B-A_B, crossed position for blue light after rotation of polarizer. The black cross formed in red light when the analyzer is set at A_R-A_R is blocked out by solid lines; the black cross formed in blue light when the analyzer is set at A_B-A_B is blocked out by dashed lines.

rotation from a polarization figure, the analyzer is rotated until the isogyres move to the center of the field and form a cross. In effect, this is compensating for the rotation or apparent rotation at the center of the field. One is, therefore, concerned only with the axial ray of the bundle passing from the polarizer to the reflecting plate, and with its component that is reflected downward from the plate to the polished surface. If the polarizer is correctly oriented, the vibration plane of this ray will not be rotated by the reflecting plate. If the polarizer is incorrectly oriented, the vibration plane of the ray will be rotated, but with monochromatic light it will only be necessary to rotate the analyzer to a new position to secure extinction at the center of the field. The angle of rotation or apparent rotation can then be measured by the usual procedure. Its values will be unaffected by the orientation of the polarizer. To prove this, one may start with the vibration plane of the polarizer either parallel or perpendicular to the axis of the reflecting plate. Using the polarization figure of an isotropic mineral, determine the crossed position of the analyzer. Next place an anisotropic mineral on the stage, and determine the extinction positions and the angle of apparent rotation for the grain. Now rotate the polarizer a few degrees to right or left. The crossed position of the analyzer will now be found to be rotated in the corresponding direction. The new extinction positions and 45° positions of the anisotropic mineral on the stage must now be found, but when the angle of apparent rotation is measured for light of a given wavelength, it will be found to be the same.

For the color phenomena of dispersion in white light, the case is different. Here we deal with the entire field of the polarization figure, and away from its center this figure is formed by inclined rays. If the polarizer is not oriented with its vibration direction either parallel or perpendicular to the plane of incidence of the reflecting plate then, since the vibration directions of the rays of various wavelengths striking the surface of the mineral are asymmetrically disposed with respect to the projected planes of vibration of the crossed polarizer and analyzer (Fig. 2), the polarization figure in white light will be asymmetrical (Fig. 3). When the analyzer is rotated first clockwise and then counterclockwise, the net result is that dispersion of the reflection rotation is accentuated in one pair of diagonally opposite quadrants of the field and diminished or even reversed in the other pair (Fig. 4).

The reader may test this by placing a polished surface of tetrahedrite on the stage and examining the polarization figure. If the polarizer is oriented with its vibration plane perpendicular or parallel to the axis of rotation of the reflecting plate and the analyzer is rotated first to the right and then to the left, the isogyres will have blue fringes on the concave sides, and the field between will be pale pinkish white. If now the polarizer is rotated, and the rotation of the analyzer is repeated, the color fringes are found to be greatly intensified in one pair of quadrants, whereas in the other they are markedly subdued. If the polarizer is rotated sufficiently, the figure shows red fringes on the concave sides of the isogyres in one pair of quadrants, blue fringes on the concave sides in the other pair of quadrants.

If chromite is used for the demonstration, the color effects are different, though the reasons are the same. If the polarizer is correctly oriented, then

the polarization figure of chromite shows only faint dispersion of the reflection rotation. Suppose we begin with the vibration plane of the polarizer parallel to the axis of rotation of the reflecting plate, and then rotate the polarizer clockwise (looking against the path of the light). Now, if the analyzer is

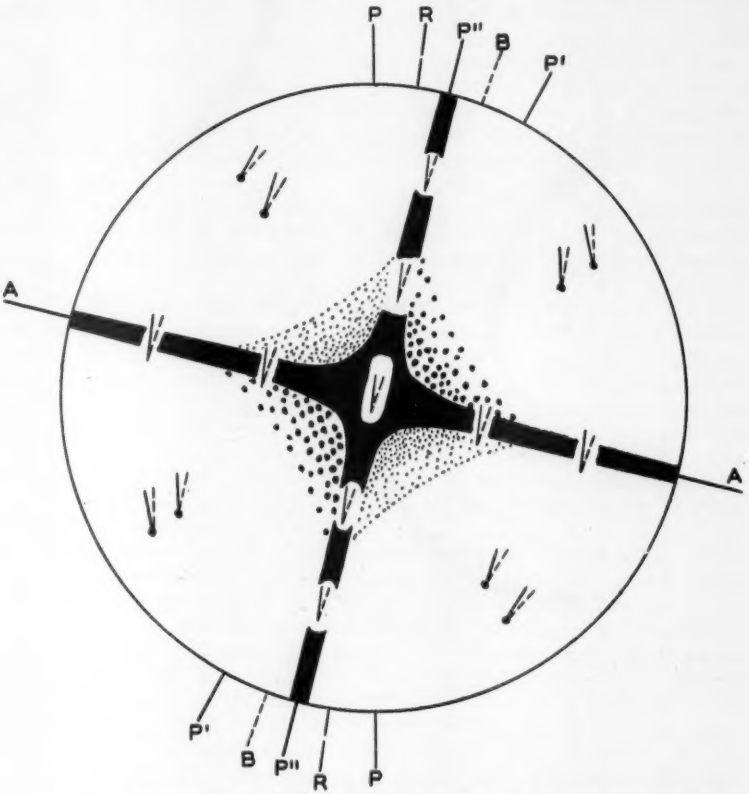

FIG. 3. Polarization cross of chromite in white light, when polarizer is incorrectly oriented. P-P, projected trace of plane of vibration of polarizer when oriented correctly, perpendicular to plane of incidence of reflecting plate. P'-P', projected trace of plane of vibration of polarizer after clockwise rotation. P''-P'', mean vibration direction for intermediate wavelengths after light coming from polarizer has been rotated by reflecting plate; R-R, vibration direction for red light after rotation by reflecting plate; B-B, vibration direction for blue light. A-A, projected trace of plane of vibration of analyzer. Short solid lines show vibration directions of rays of red light reflected from polished surface of an isotropic mineral; short dashed lines show vibration directions for blue light. Coarse dots indicate reddish coloration of field; fine stippling indicates bluish coloration of field.

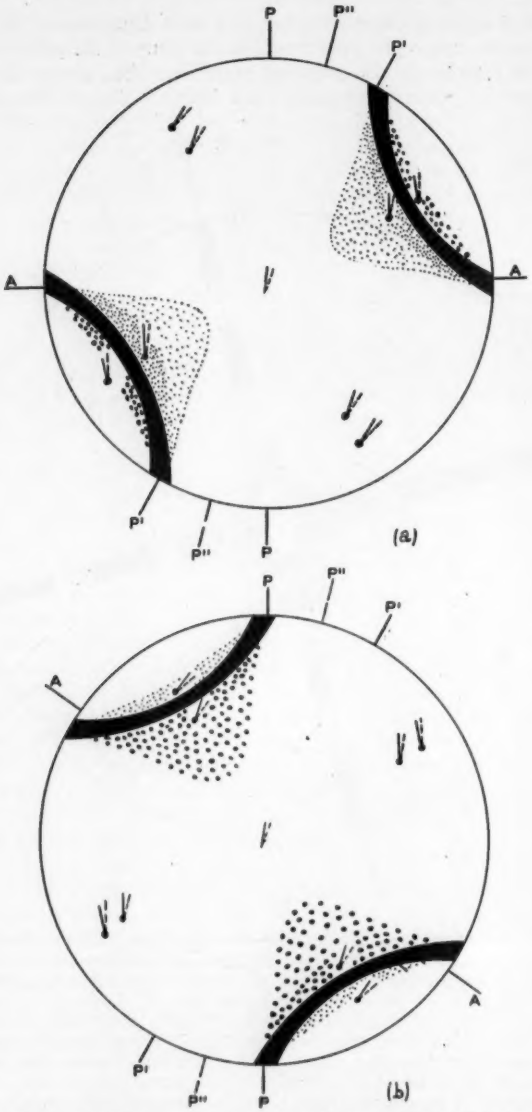

FIG. 4. The conditions are the same as for Fig. 3, but in (a) the analyzer has been rotated counterclockwise from its position in Figure 3, whereas in (b) the analyzer has been rotated clockwise. Notation and symbols as in Fig. 3.

rotated successively to left and right, the isogyres in the northwest and southeast quadrants will show distinct red fringes on the concave sides and distinct blue fringes on the convex sides. If the polarizer is rotated sufficiently, the color fringes are reversed in the northeast and southwest quadrants, red appearing on the convex sides, blue on the concave sides.

Comparable effects are produced in the figures of anisotropic minerals when these are at positions of extinction. If a mineral has strong dispersion, a small error in orientation of the polarizer will not be enough to suppress or reverse the dispersion of the reflection rotation in either pair of quadrants, and errors in interpreting color fringes are not likely, but with minerals of weaker dispersion, anomalies occur and errors in interpretation of fringes are easily made.

Comparable effects are produced in the color fringes of the polarization figures of anisotropic minerals at the 45° positions, and may easily lead to errors in qualitative determination of the dispersion of the apparent angle of rotation.

To check the orientation of the polarizer, the following procedure is recommended. Place a section of chromite or other isotropic mineral of medium reflectivity and low dispersion on the stage and rotate the polarizer until isogyres of equal blackness are formed successively in both sets of quadrants when the analyzer is rotated. Now set the analyzer at the crossed position, using the polarization figure to do so. Next, place a section of covellite on the stage and determine the extinction positions. These should be 90° apart. At each extinction position, the quadrants of the field should be uncolored.

The above procedure is effective provided the objective is free of strain, as discussed in the following section.

Strain in the Objective.—Strain in the objective is the most serious source of error that we have found. The qualitative effects produced by it are much the same as those produced by incorrect orientation of the polarizer—anomalous dispersion and asymmetrical dispersion. Strain in an objective is easily detected by rotating the objective in its mount while observing the polarization figure of an isotropic mineral. If the objective is not strained, the black cross shows no change during a 360° rotation of the objective. If the objective is slightly strained, the center of the cross becomes alternately black and gray four times during a 360° rotation. If more serious strain is present, the figure is a cross only at four positions of the objective 90° apart. At intermediate positions the figure consists of two isogyres, the maximum separation of which is proportional to the degree of strain of the objective.

For convenient reference, refer to the four positions of the objective at which the figure is a cross as the "positions of no apparent strain," and the intermediate positions as the 45° positions. By setting the objective at one of the positions of no apparent strain, asymmetrical and anomalous dispersions, as indicated by color fringes, can be corrected. Numerous experiments with a series of objectives show, however, that values of the angle of apparent rotation for anisotropic minerals obtained with a strained objective in general depart from the true values, even if the objective is set at a position of no apparent strain. It can be shown theoretically that the departure of measured

values from the true values may range from 0° upwards. The actual amount of departure in a given case is a function of the difference in amplitude of the reflected components corresponding to the two vibration directions of the mineral, the phase difference between the two components, the retardation imparted by the objective, and the orientation of the fast and slow rays of th objective with respect to the plane of the polarizer. From the standpoint of practicable measurement, the net result is that strained objectives are unsatisfactory and their use in the study of rotation properties is undesirable.

For some time after the first work on rotation properties was done in this laboratory, objectives free of strain were found very difficult to obtain. However, we now have ten objectives that are free of strain or so nearly free as to be entirely usable. These have been provided through the efforts of the late Mr. J. D. Reardon of American Optical Company and Mr. J. R. Benford of Bausch and Lomb Optical Company. Their interest in work on rotation properties led them to re-examine and modify the procedures by which objectives for use with reflected light are selected and factory-tested for freedom from strain.

Effect of Refraction in Objectives.—It has long been known that the refraction of rays in passing through an objective causes rotations of the vibration directions of all rays except the rays that pass along the tube axis of the microscope and hence are vertically incident on the air-glass boundaries and the surfaces separating the lenses. Indeed, the very production of polarization figures is dependent upon these rotations as shown by Wright (9, p. 187; 10, p. 795–803) and Inoué (7). Inasmuch as apparent angles of rotation are measured by compensation at the optical center of the field, which is illuminated by the axial pencil, the apparent angles of rotation should not be affected. A series of tests made with 20 ×, 40 ×, and 43 × objectives obtained from Bausch and Lomb Optical Company and American Optical Company supports this. The tests were made on diversely oriented grains of molybdenite showing values of the apparent angle of rotation of 3° to 11°. The values obtained were identical for all objectives within the usual limit of error of measurement ($\pm 0.2°$ to $\pm 0.3°$).

For dispersion of the isogyres, the situation is different. The isogyres are formed by convergent rays, and rotation of the planes of vibration of these rays in passing down through the objective is inevitable. On reflection at the surface of the mineral, the rays are further rotated. Rotation in the objective on the upward passage through the objective will therefore not be equal and opposite to the rotations on the downward path. Inasmuch as the lens system varies with the type and aperture of the objective, effects theoretically should be different for each kind of objective.

Formulae exist by which all these rotations can be calculated, but since in practice we are concerned with qualitative interpretation of color fringes, only the qualitative influence of these rotations is important. We have, therefore, chosen the simpler procedure of comparing dispersion effects produced with various objectives. Effects do vary with the kind of objective, but the variations are only in the distinctness of the color fringes. We find, however, that for objectives of a given aperture and of a single make and model, there

is no detectible difference in intensity of color fringes. As would be expected, however, color fringes are broader with objectives of lower aperture. We have obtained optimum results with a 6 mm, N. A. 0.65 Bausch and Lomb objective. Objectives of lower aperture give figures that are too dull and diffuse to be satisfactory.

Tilting of the Section.—The theory of polarization figures assumes that the mineral surface being examined is perpendicular to the tube axis of the microscope. This can be achieved in practice by using some sort of leveling device, but as this complicates examination, a series of tests has been run to determine the effects of tilt. For this purpose, the surfaces examined were mounted on a special stage that can be tilted through measurable angles. Results of measurements for ilmenite, a mineral of low angle of apparent rotation, are given in Table 1, and results for molybdenite, a mineral of high rotation, are shown in Table 2. In both tables "Tilt" designates the angular deviation of the polished surface from the perpendicular to the tube axis of the microscope. When a section is tilted, the center of the polarization figure is displaced from the center of the field. The displacement of the center of the cross when the mineral was at an extinction position was estimated in terms of the field diameter.

TABLE 1.

EFFECT OF TILT OF THE POLISHED SURFACE ON VALUES FOR A_r OF ILMENITE.

Tilt	Displacement of center of figure from center of field. Mineral at extinction	Mineral at 45° position: Ratio of the distances of the two isogyres from the edge of the field	A_r
0°	No displacement, figure centered	x:x	2.4
1°	No noticeable displacement	x:x	2.4
2°	±5% of field diameter	x:$1\frac{1}{2}x$	2.4
3°	10%–15% of field diameter	x:$2x$	2.5
4°	15%–20% of field diameter	Surface cannot be rotated to 45-degree position	Not measurable, objective strikes mount
5°	25% of field diameter	Surface cannot be rotated to 45-degree position	

The data indicate that with minerals of low rotation, the angle of apparent rotation is not affected significantly if tilt of the section is less than 4°. Tilting of more than 2° is readily detected by displacement of the figure in the field. The data for molybdenite show that with higher rotations, a tilt of 2° produces an error of 0.3° in the measurement of A_r. Before large angles of rotation are measured, therefore, sections giving off-center figures should be leveled.

Effect of Ellipticity.—The statement has often been made in the literature (e.g., 8, p 25) that the vibration ellipses of light reflected from ore minerals in

general are extremely narrow, hence that they approach linear vibrations. In studies of polarization figures, however, it has been noted that if grains of certain minerals are placed at a 45° position and an attempt is made to measure the apparent angle of rotation, measurement is difficult because only a vague cross is formed at the compensation point. The precise point of compensation for some minerals cannot be determined. Covellite and umangite are outstanding examples, and empressite, rickardite, and nagyagite (6, p 811–813) are others. With covellite, the cross formed when the analyzer is rotated is only a shadow, if red light is used. By contrast, in blue light a black cross is formed.

This problem has been investigated by means of an elliptical vibration compensator (8). With covellite, the rotation for grains cut parallel to the

TABLE 2.

EFFECT OF TILT OF THE POLISHED SURFACE ON VALUES FOR A_r OF MOLYBDENITE.

Tilt	Displacement of center of figure from center of field. Mineral at extinction	Mineral at 45° position: Ratio of distances of the two isogyres from the center of the field	A_r
0°	No displacement, figure centered	$x:x$	11.6 ± 0.2°
1°	Less than 5%	$x:x$	11.4 ± 0.2°
2°	5%–10%	$x:1\frac{1}{2}x$	11.3 ± 0.2°
3°	10%	$x:2x$	11.2 ± 0.2°
4°	15%–20%	$x:2x$	11.3 ± 0.2°
5°	20%	Surface cannot be rotated to 45-degree position	

c-axis is so high that it lies beyond the range of the compensator. A grain showing rotation angles of 7.9° for red light and 2.2° for blue light, however, gave phase differences of 11° and 1°, respectively, for the two wavelengths. Umangite likewise shows higher ellipticity for red than for blue. A grain near the orientation for maximum anisotropism of this mineral gave a phase difference of 18.0° for red light, a phase difference of only 2.5° for blue light. The rotation for red is only 1.3°, for blue 1.5°.

Although ellipticity causes difficulties in measuring apparent angles of rotation, it has potential value in that it is itself a property that can be used in mineral identification if ore microscopes can be equipped to measure it.

Failure to Cross the Nicols Exactly.—In the paper by Cameron and Green (3, p 751), the necessity of crossing the nicols precisely when observing dispersion effects and measuring apparent angles of rotation was emphasized. Experience has indicated that precise crossing is essential in observing dispersion color effects, weak effects particularly. For evaluation of the effects of imperfect crossing of the nicols on measurements of angles of apparent rota-

tion, a series of measurements of A_r for a single grain of molybdenite has been made. These are given in Table 3.

For the first series of measurements, the analyzer was crossed with the polarizer as precisely as possible, the extinction positions determined, and A_r measured first at a position 45° clockwise from an extinction position, then at a position 45° counterclockwise. For the second and third series of measurements, in each case the new extinction positions were determined. The mineral was then rotated clockwise from one extinction position halfway to the next extinction position, and A_r was measured. The mineral was then rotated counterclockwise from the original extinction position to the halfway point, and A_r measured. The data show that if the analyzer is a degree off the crossed position, the value measured at one intermediate position is greater than that measured at the other, but the average is the same, within the limits of error of measurement, as the values obtained with the analyzer precisely crossed. Experience indicates that by use of the

TABLE 3.

MEASUREMENTS OF THE ANGLE OF APPARENT ROTATION OF A GRAIN OF MOLYBDENITE.

Position of analyzer	A_r (uncorrected for effect of reflecting plate)		
	Mineral rotated clockwise	Mineral rotated counterclockwise	Average
1. Crossed	14.2 ± 0.2	14.0 ± 0.3	14.1
2. One degree clockwise from crossed position	13.0 ± 0.4	15.3 ± 0.3	14.15
3. One degree counterclockwise from crossed position	15.3 ± 0.3	13.2 ± 0.2	14.25

polarization figure of an isotropic mineral, the analyzer can be crossed with the polarizer with an error of less than half a degree. The more elaborate procedure for crossing the nicols recommended by Cameron and Green (3, p 743) is therefore unnecessary for purposes of measuring angles of apparent rotation. This is important, for precise crossing is sometimes tedious and time-consuming, whereas crossing by use of the polarization figure of an isotropic mineral can be done in a few seconds.

The error due to imprecise crossing of the nicols should increase in general with the size of A_r. Molybdenite was chosen for the test because its angle of apparent rotation is higher than the angles for most ore minerals. For lower angles of apparent rotation, the error should be even smaller, and supplementary experiments support this inference.

Rotation Produced by the Reflecting Plate.—In the course of his study of polarization colors, Green (5) found that if the prism reflector is used, values for the apparent angle of rotation measured by the method of extinction differ significantly from values obtained by measurements from the polarization figures. This discrepancy has been traced to the reflecting plate. If an isotropic mineral is placed on the stage, incident rays vibrating parallel or per-

pendicular to the plane of incidence of the reflecting plate are reflected back through the plate toward the analyzer without rotation of their vibration directions. Rays rotated by reflection from an anisotropic mineral, when it is not at an extinction position, strike the reflecting plate with a vibration direction that is neither parallel nor perpendicular to the plane of incidence of the plate. In passing through the plate these rays suffer a further rotation in the same sense as that produced by the mineral.[4] The value of the apparent

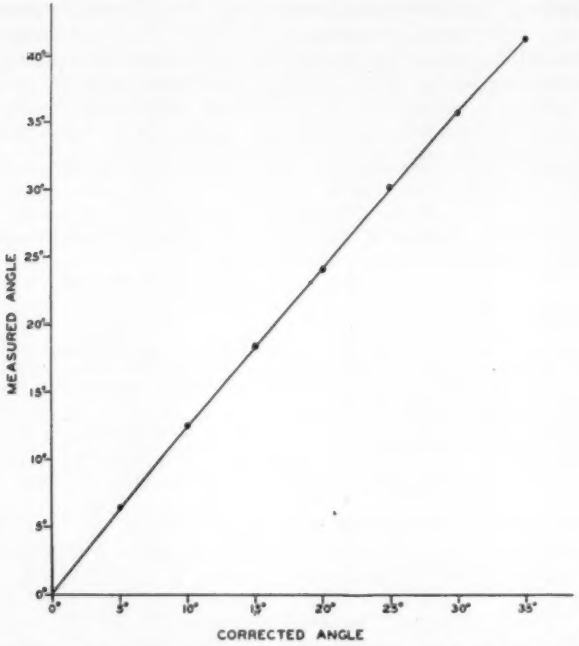

FIG. 5. Curve for correcting measured apparent angles of rotation for the error introduced by the reflecting plate.

angle of rotation measured by means of the analyzer is therefore higher than the true value. The additional rotation imparted by the plate increases with increase in the rotation produced by the mineral. A correction curve must therefore be drawn up for each microscope. Correction curves drawn up for six Spencer microscopes of the same model in our laboratory gave curves that are similar in form but differ in the absolute values of corrections for various measured angles. According to the late J. D. Reardon of American

[4] In addition, for all wavelengths for which the optical thickness of the plate is not one-quarter wavelength, a coated plate introduces a retardation, but this is too small to be significant.

Optical Company (verbal communication), this is because the thickness of the coating is not the same for every reflecting plate.

Figure 5 shows the correction curve for one of the microscopes in this laboratory, and Figure 6 shows the data on which it is based. Theoretically, the rotation produced by the plate should be a function of the wavelength of light used. As indicated in Figure 6, however, curves for red, blue, and white light are the same within the limits of error of measurement ($\pm 0.2°$).

Measurements on which these curves are based were made in the following manner. The microscope was set up for observation in transmitted light.

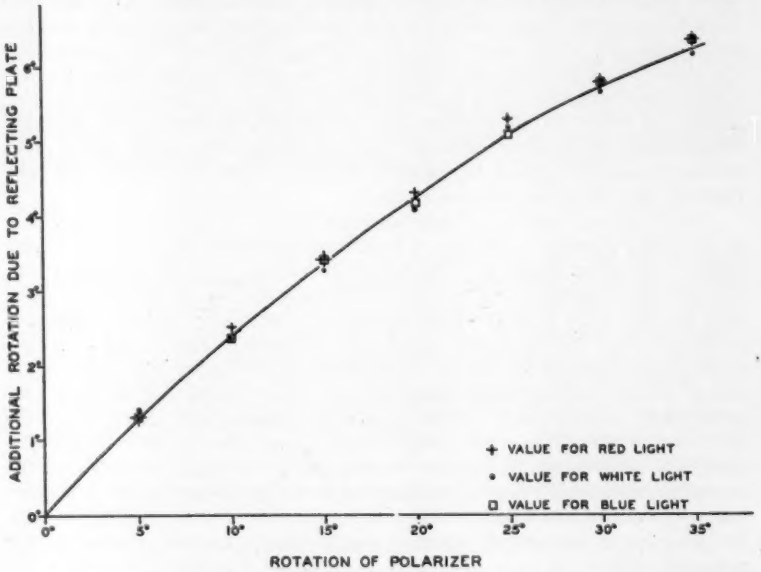

FIG. 6. Curve showing additional rotations introduced by the reflecting plate for various wavelengths. The rotations of incident vibrations produced by anisotropic minerals are simulated by rotation of a substage polarizer. At 0°, the vibration plane of the polarizer is perpendicular to the plane of incidence of the reflecting plate. Based on observations with a Spencer microscope.

The substage polarizer was used, and a cap nicol was crossed precisely with it by use of a Wright bi-quartz wedge. The reflecting plate was then inserted and the vertical illuminator rotated on the tube axis until the plate produced no rotation of the light passing upward from the analyzer. The polarizer was then rotated to positions successively 5°, 10°, 15°, 20°, 25°, 30°, and 35° from the zero position. At each position, the rotation of the analyzer necessary to produce extinction was determined. The difference between this rotation and the rotation of the polarizer is equal to the rotation produced by the plate.

If the microscope has no substage polarizer, the corrections must be determined by comparing values of the rotation produced by differently oriented grains of a highly anisotropic mineral (molybdenite is suitable for this purpose) as measured first with the reflecting prism, then with the reflecting plate.

Effect of the Surface Film.—It has long been known that polishing tends to produce a flowed layer at the surface of a mineral, and various discussions of this subject have appeared (e.g., 1, p 29–30; 94–103). The effects on optical properties are known to vary with the mineral, with the optical parameter under consideration, and with the polishing method used. Available data (2, p 63) suggest that the effects in general are greater for the softer and less brittle minerals. With these minerals, polishing lowers reflectivity and affects the ellipticity of the reflected vibrations. The effects are at a minimum for vertical incidence, increasing as the angle of incidence of light increases. According to Berek, though reflectivities are lowered, the ratio of the uniradial reflectivities, which determines the angle of apparent rotation for a given anisotropic mineral, is not significantly affected. This is a subject, however, that will have to be investigated further.

Suitability of Currently Produced Microscopic Equipment for the Study of Rotation Properties.—Studies of rotation properties in this laboratory have thus far been done largely with the Bausch and Lomb Model O ore microscope and with the Spencer petrographic microscope (Models 42 and 43, equipped with the No. 2530 vertical illuminator and accessories). Neither apparatus is ideally suited for the study of rotation properties. The Model O microscope is equipped with a polarizer cemented to the downward face of the prism, and no provision is ordinarily made for a polarizer for use with the reflecting plate. The manufacturers furnish, however, a polaroid disc that fits into the filter slot in the tube of the vertical illuminator between the two iris diaphragms. This must be fastened in the slot by tapping two holes in the mounting of the slot. Set screws inserted in the holes serve to fix the polarizer. The entire tube can be rotated on its axis, hence it is possible to rotate the polarizer to the proper position parallel to the axis of rotation of the reflecting plate.

The Spencer apparatus as usually furnished has two principal defects. One is the fact that the entire vertical illuminator is mounted in an objective collar. Each change in objective requires recentering, a tedious nuisance. Furthermore, the centering of the objective is easily disturbed. This difficulty is readily overcome. If the "quick-change centering nosepiece" is removed from the lower end of the body tube, the vertical illuminator can be screwed directly into the lower end of the microscope tube. The objective adapter mount can then be removed from the lower end of the vertical illuminator, and a "monobjective adapter" inserted in its place. The quick-change centering nosepiece which was removed from the body tube is now inserted into the monobjective adapter. Each objective can now be kept in its own centering collar, and the need for constant recentering is thereby eliminated.

The other, and more serious defect, is in the mounting of the polarizer. This is a plate that fits into a slot in the body tube and is held in position by

a pin. Tests of six illuminators in our laboratory indicate that the orientation of the polarizer is not always correct. The error may be more than a degree. If the error is small, there is enough play in the mounting so that the plate can be rotated to the proper position and held by a wedge of cellophane tape fastened to the underside of the plate, but modification of the mounting to permit the plate to be rotated to the proper position and clamped there is needed.

Both microscopes have an additional defect in that the analyzer scales are graduated at 5° intervals. One can mount his own scale, using a part of a celluloid scale (from a boxwood scale) divided into 80ths or 100ths of an inch. For accurate readings, however, a vernier is highly desirable.

We have had no opportunity to examine the microscopes manufactured by E. Leitz since World War II. A prewar Leitz microscope in our laboratory was originally equipped with a simple glass reflecting plate, with which illumination was too low. It since has been equipped with a coated reflecting plate, and if this is used, fairly satisfactory figures are obtained.

SUMMARY AND CONCLUSIONS.

Various sources of error in the optical system of the ore microscope have been investigated and evaluated. Most involve matters of proper adjustment of the microscope, and these sources are readily eliminated or reduced below the significant limits of measurement. Two sources, however, merit particular attention. One is the presence of strain in the objectives used. At best, strained objectives add to the labor of determining rotation properties. At worst, they may lead to serious errors. Their use is therefore to be avoided. The second source of error is the reflecting plate. This error cannot be avoided, but measured values of apparent angles of rotation can be corrected to the true values by reference to a curve that can be readily constructed.

Modifications of some existing microscopic equipment are needed to facilitate study of rotation properties.

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May 18, 1953.

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THE TEXTURAL PATTERN OF THE SERPENTINES.

BARTHOLOMEW NAGY.

ABSTRACT.

A large number of serpentine specimens have been studied and found to be either chrysotile or antigorite or mechanical mixtures of these two minerals. Electron microscopic examination, HCl solubility tests, X-ray diffraction, and differential thermal analyses reveal the existence of such a mixture in an unknown serpentine sample. Evidence indicates that one mode of formation of antigorite may involve the recrystallization of chrysotile. It is possible that the fibrous antigorite present in narrow veins that surround and/or penetrate larger antigorite grains was formed by such a process.

INTRODUCTION.

A LARGE number of serpentine samples have been studied and found to be either chrysotile or antigorite or mechanical mixtures composed of variable proportions of these two minerals. Species names other than chrysotile and antigorite are not justified and should be abandoned.

Chrysotile and antigorite are both hydrous magnesium silicates (with the general chemical formula of $3MgO \cdot 2SiO_2 \cdot 2H_2O$) and appear to have similar crystal structures. Warren and Hering (16)[1] concluded that chrysotile has a layer structure composed of a silicon-oxygen sheet and a magnesium-hydroxide (brucite) sheet. Because these two basic units have different sizes the resultant double layer is curved according to the prediction of Pauling (10). The chrysotile fibers look like hollow tubes on the electron micrographs; this phenomenon was first observed by Turkevich and Hillier (15) and discussed by Bates, Sand and Mink (3). Aruja (1) found that the antigorite crystal structure is based on the same two fundamental units; however, the morphology of antigorite is not tubular but flaky or lath like. This is due, according to Bates and Mink (2), to replacement of some of the Mg^{++} ions by trivalent cations (chiefly Al^{+++} and Fe^{+++}), which results in the reduction of the size difference between the silicon-oxygen and brucite layers. The majority of the chemical analyses available seem to support this hypothesis, since the Al_2O_3 and Fe_2O_3 content of antigorites is generally higher than that of the chrysotiles.

Selfridge (11) has shown that the serpentine minerals resemble either chrysotile or antigorite and he has suggested that the features by which the species differ indicate only different modes of formation. Nagy and Bates (7) mentioned that serpentines other than chrysotile and antigorite are generally mechanical mixtures of these two minerals.

THE CHRYSOTILE-ANTIGORITE MECHANICAL MIXTURES.

Electron micrographs of serpentines other than chrysotile and antigorite generally show both flaky and fibrous (tubular) particles, thus indicating the

[1] Numbers in parentheses refer to Bibliography at end of paper.

presence of both antigorite and chrysotile. The predominant crystal habit is most commonly flakes and/or irregular particles that are believed to consist of fragments of larger flakes crushed in the grinding process during the preparation of samples. Figure 1 shows an electron micrograph of a serpentine from Montville, New Jersey, which is a mechanical mixture of chrysotile and antigorite. It is often possible to detect the presence of both of the components in thin sections with the aid of an ordinary petrographic microscope. In such cases chrystotile is most commonly present in very narrow veins that surround and/or penetrate the larger antigorite grains.

The X-ray diffraction pattern of chrysotile is destroyed after leaching the fibers in 1 normal hydrochloric acid at 95° C for one hour. To achieve the

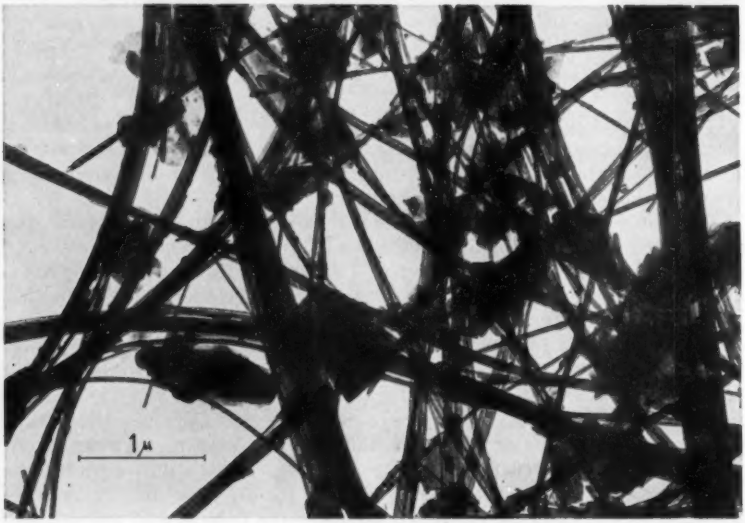

FIG. 1. Electron micrograph of serpentine from Montville, New Jersey, showing a mechanical mixture of chrystotile fibers and antigorite flakes. × 19,850.

same results antigorite has to be subjected to concentrated HCl treatment. After a chrysotile-antigorite mixture has been subjected to leaching in 1 normal hydrochloric acid the chrysotile lattice ceases to contribute to the intensities of the X-ray reflections, which accordingly will have lower values than they had before the treatment. Such a relationship is expected to be valid when the two components have similar absolute surface areas. Using this different behavior of the two minerals it was possible to confirm the electron-microscopic data as to the presence of mixtures. Figure 2 shows tracings of the X-ray spectrometer patterns of the 001 reflections of antigorite, chrysotile, and the serpentine from Montville, New Jersey, after treatment with 1 normal hydrochloric acid.

Differential thermal analysis data support the previous results. Leaching in 1 normal HCl results in the disappearance of the high temperature endothermic peak of the chrysotile pattern, but it has no effect on the antigorite curve. Figure 3 shows tracings of the DTA curves at the high temperature endothermic reaction of 1 normal HCl treated chrysotile and antigorite and of the serpentine from Montville, New Jersey.

SOME ASPECTS OF GENESIS.

In the last decade two paths were generally followed in the search for an understanding of the genesis of the serpentines. One of the paths involved

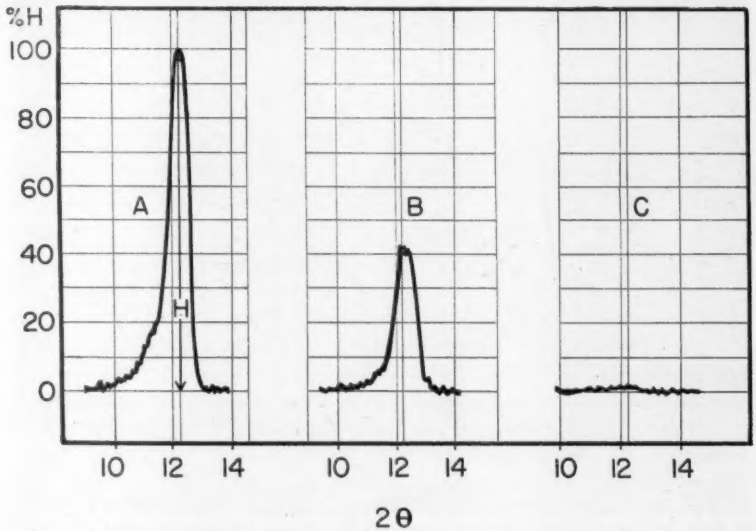

FIG. 2. Tracings of the X-ray spectrometer patterns of the 001 reflections of 1 normal HCl treated antigorite from Antigorio valley, Piedmont (A), serpentine from Montville, New Jersey (B), and chrysotile from Thetford, Quebec (C). Instrument settings, sample preparation, volume of sample and mesh size were identical in all three runs. The runs were made with Cu Kα radiation on a North American Philips X-ray spectrometer. Vertical scale represents fractions of the height of peak (A) in order to emphasize the relative differences.

attempts to synthesize the serpentine minerals and work out their phase equilibria relations; the other approach included the study of natural minerals and field occurrences. The synthesis of chrysotile was achieved without great difficulty; the attempts to synthesize antigorite, however, led only to uncertain results.

The study of Bowen and Tuttle (4) of the system $MgO—SiO_2—H_2O$ established that chrysotile can be formed at temperatures below 500° ± 10° C

and pressures ranging between 2,000 and 40,000 psi., but did not result in the synthesis of antigorite.

Strese and Hofmann (13) claimed to have obtained antigorite from alkali silicate and magnesium chloride solutions; however, Epprecht (5) found that the evidence was not sufficient to make such a claim. Noll (9) observed under the electron microscope a flaky substance, which he obtained by introducing KOH to the system. The properties of this product, however, were not conclusive enough to call it antigorite. Epprecht confirmed Noll's results by adding KOH to the starting mixture of $2SiO_2 \cdot 3MgO \cdot 2H_2O$ and concluded that, "ein Kali-Zusatz scheint . . . die Bildung von Antigorit zu begünstigen."

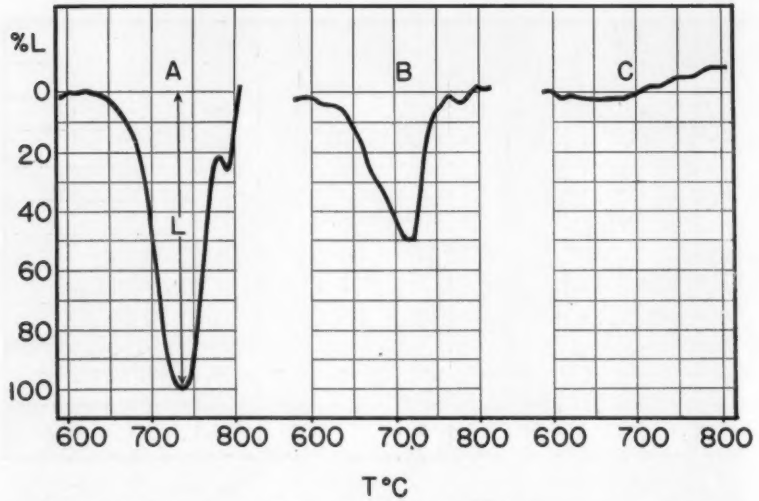

FIG. 3. Tracings of the differential thermal analysis patterns at the high temperature endothermic reaction of 1 normal HCl treated antigorite from Antigorio valley, Piedmont (A), serpentine from Montville, New Jersey (B), and chrystotile from Thetford, Quebec (C). All three runs were made in the same differential thermal analysis unit and sample block at the same amplification and heating rate. The amount and mesh size of the sample were also the same in all three runs. Vertical scale represents fractions of the height of peak (A) in order to emphasize relative differences.

Another approach was reported by Tu (14) who, working under J. W. Gruner at the University of Minnesota, found that the addition of Al_2O_3 to the system results in a flaky serpentine outside the temperature range of 370°–460° C. Yoder (17) concluded on the basis of his work on the system MgO—Al_2O_3—SiO_2—H_2O that flaky aluminous serpentine is formed below approximately 520° C and water vapor pressures ranging between 2,000 and 30,000 psi. from a mixture of $5MgO \cdot Al_2O_3 \cdot 3SiO_2$. Some of the properties of this substance appeared to differ from those of the natural antigorite.

A third approach was followed by the author during the course of the present study but it did not lead to more conclusive results. In a recent paper Nagy and Bates (8) came to the conclusion that chrysotile is less stable than antigorite, because the chrysotile tubes are affected by less severe chemical and physical treatments than the antigorite flakes. Following this lead, attempts were made during the present study to obtain antigorite from chrysotile by assuming that after the chrysotile tubes were flattened out by acid treatment they may recrystallize as antigorite if the conditions are favorable. This assumption was supported in part by the fact that chemical analyses of antigorite present in the literature sometimes have as little as 1.03% Al_2O_3 and 0.90%

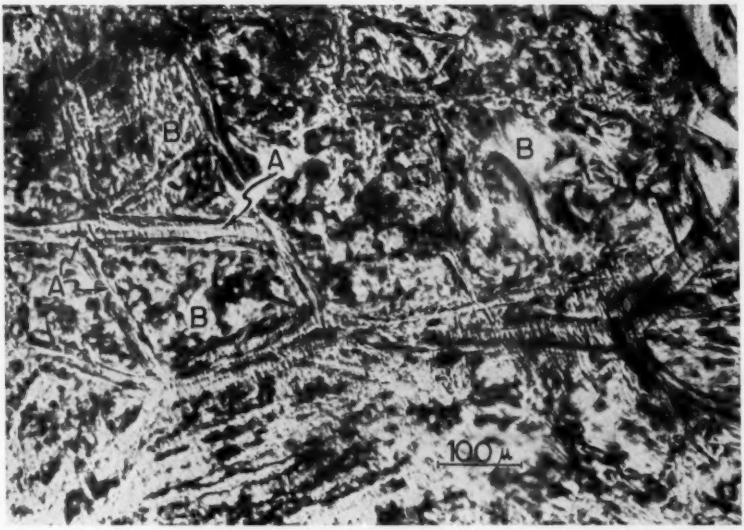

FIG. 4. Photomicrograph of serpentine from Lafayette, Montgomery County, Pennsylvania, showing veins of fibrous antigorite (A) in massive antigorite (B). × 132.

Fe_2O_3, as reported by Hess, Smith and Dengo (6). Chrysotile fibers from Thetford, Quebec and Globe, Arizona, were ground to approximately 0.5 μ length and put in a gold lined bomb together with 0.01 normal HCl and kept at 300°–400° C temperatures and 10,000 psi. pressure for an average of three days. The hydrochloric acid extracted the magnesium from the chrysotile lattice and caused the tubes to collapse; meanwhile the solution became neutral or slightly alkaline. Both flaky particles and tubular fibers developed, the former presumably by the redeposition of Mg^{++} ions on the flattened out silica remains of the chrysotile tubes. However, it was impossible to decide whether the flaky particles were antigorite. Collapsed chrysotile and $Mg(OH)_2$ in water yielded chrysotile and a product that is most likely brucite.

Sobolev (12) concluded on the basis of field evidence that chrysotile may change into antigorite under favorable conditions. Hess, Smith and Dengo described antigorite from Venezuela, which was derived according to these authors from chrysotile under dynamothermal metamorphism. The Al_2O_3 and Fe_2O_3 content of this antigorite was lower, but the silica content was higher than usual.

A critical study of thin sections of serpentines suggests that recrystallization of chrysotile into antigorite may be more common than is generally regarded. Careful optical investigations of the fibers present in tiny veinlets that often surround and/or penetrate the larger antigorite grains have in some instances led to the identification of antigorite. The texture and overall appearance of such fibers are the same as those of chrysotile; the optical properties, however, are those of antigorite. Such an example is shown in Figure 4. Since the fibers in these veins appear to be formed later than the rest of the serpentine sample, and furthermore because they resemble chrysotile which is present in similar veins, one gets the impression that the antigorite was derived from chrysotile.

An evaluation of recent studies suggests that the serpentine mechanical mixtures might have developed by the following processes: (1) in the presence of available Al^{+++} and Fe^{+++} ions crystallization of antigorite followed by the crystallization of chrysotile generally around or between the already formed antigorite grains, (2) formation of antigorite through partial recrystallization of chrysotile, and (3) by the combination of both of these processes.

Antigorite formed from chrysotile would have a lower Al_2O_3 and Fe_2O_3 content than the antigorite formed from other sources. Such an antigorite may be similar to the sample from Venezuela which was described by Hess, Smith and Dengo.

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DISCUSSION

NOTES ON CHROMITE DEPOSITS IN SAMAR, PHILIPPINES

A number of small but high-grade chromite deposits are known in the valley of the Suribao River, near the east coast of Samar, 13 to 16 km South and South-Southwest of Borongan. They were visited and sampled during several days in 1951. Later, a few exploration trenches were dug but they succeeded in finding only about 1,000 tons of chromite. Nevertheless, the region seems worthy of more detailed geological study as a possible future source of metallurgical-grade chromite.

Around Hunop, about 6 kilometers up the river from the village of Suribao, and 2 kilometers south of the river, is a serpentine area probably at

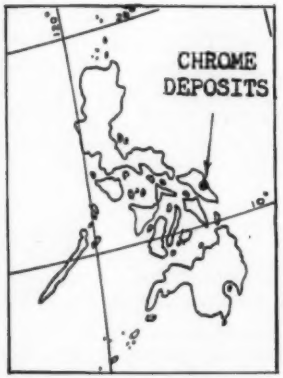

FIG. 1. Index map.

least 1 1/2 miles in diameter. The serpentine is greenish, and highly fractured and compressed, containing small quartz veins that have also suffered deformation. Embedded, apparently at random, in the serpentine are small massive chromite bodies of the "sack-form" type. A few were uncovered enough to reveal in part their size and shape. Sketches of them in plan are shown in Figures 2, A-D. The two larger bodies shown in Figure 2A are roughly oval in vertical cross-section; they are nearly cigar-shaped. The largest body found (Fig. 2C) seems to be a flat-dipping slab.

The chromite ore is black to brownish and mostly rather friable with grain size from a fraction of a millimeter to several millimeters. Scanty shreds

of antigorite are the only gangue. Five samples of outcrops, float and ore stockpiles around the deposits shown in Figure 2A gave the following average analysis: Cr_2O_3 56.27%; Cr 38.50%; Fe 12.43%; SiO_2 1.47%; Cr/Fe 3.09.

The serpentine is overlapped by Tertiary limestone, shale and brown coal beds, gently folded. The serpentine basement is exposed in a second place along the Suribao River, starting at a point about 6 or 7 kilometers upstream

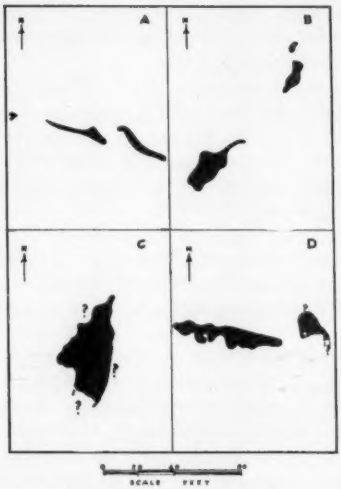

FIG. 2. Sketch plans of chromite deposits near Suribao River, Samar, P. I.

from the first area. Small chromite outcrops occur in this serpentine at a place called Matinao, 18 to 20 km above Suribao and a few hundred yards above the north bank of the river. Samples taken here across a chromite ledge 2 1/2 to 4 feet wide gave the following analytical results: Cr_2O_3 54.54%; Cr 37.32%; Fe 12.10%; SiO_2 1.44%; Cr/Fe 3.08.

W. C. STOLL.

BALATOC, P. I.,
Sept. 8, 1953.

DEFINITION OF A MINERAL BELT IN SOUTH CENTRAL COLORADO.

Sir: In John W. Gableman's significant paper, *Definition of a Mineral Belt in South Central Colorado* (this JOURNAL, May, 1953), reference is made to the Bull-Domingo agglomerate as a pipe of explosion breccia. On the basis of an underground examination, made in 1949, the writer considers the pipe to have few characteristics of an explosion breccia. There are indications that the pipe occupies the throat of a boiling spring in which blocks loosened

from the walls were churned by convection in a medium of finer rock fragments.

Features of the Bull-Domingo pipe that have been taken into consideration are:

1. The form of the pipe—irregular and relatively narrow (1,000 feet of known depth and 100 to 200 feet in diameter). Small subsidiary exposures of agglomerate, and a small additional pipe intersected underground, give indication that the main structure branches upward. Rather than coinciding with the crater-like result of an explosion, the form of the pipe suggests a centralized hot spring area with minor branches.

2. The agglomerate is composed entirely of Precambrian rocks that are known to be cut by the pipe. No volcanic fragments have been noted.

3. The agglomerate seems to have a similar composition throughout the pipe. Gneiss, syenite, and pegmatite occur in about the same proportion among boulders, pebbles, and fine matrix. A thorough mixing is indicated, as would be expected in a boiling spring.

4. With the exception of those in the main ore sheet, which occupies an irregularly branching zone of open interstices, the boulders are held in a solid and impermeable matrix of finer material. The entire mass is so compact that workings will stand for about two weeks without timber. Fissures adjacent to the pipe are filled with solid agglomerate. The material within the pipe is not an open rubble, but rather a thoroughly compacted mass.

5. All of the boulders show effects of attrition. Gneiss boulders are generally rounded, pegmatite boulders are sub-rounded, and hard syenite boulders are subangular. The rounding of boulders would be an expected result of churning in a boiling spring. Nearly all of the boulders, especially the gneiss boulders, have alteration rims which would account for some rounding. The rims are, however, thickest in the vicinity of ore shoots and near the walls of the pipe, indicating association with mineralization rather than with the formation of agglomerate.

In the opinion of the writer, the Bull-Domingo agglomerate pipe represents a boiling spring which formed in an area of intersecting faults and was enlarged to its present size by churning rock debris. The ore shoots are believed to occupy channelways which were kept free from matrix by ascending waters during the dying stage of the spring.

W. C. PETERS.

IDAHO STATE COLLEGE,
POCATELLO, IDAHO,
May 26, 1953.

CORYCIUM DEFUNCTUM: THE NON-INDICATIVE PROPERTIES OF ISOTOPES AND REVIEW ARTICLES.

Sir:—In a recent review of the data on natural variations in stable isotopic abundances (1), M. L. Jensen states that carbon from plant sources can " . . . often be distinguished from inorganic carbon since plants favor the lighter C^{12} isotope, which of course results in a relatively higher C^{12}/C^{13} ratio. It has,

therefore, been possible to determine if graphite, more commonly Precambrian graphite, represents organic carbon. . . . " This statement refers to a recent investigation by Rankama (2) of certain carbonaceous deposits from the Precambrian of Finland, including some late Archean carbonaceous accumulations that had been named *Corycium enigmaticum* by Sederholm, in the belief that they represented remains of primitive plants. From comparison of the carbon isotopic composition of this material with the range of isotopic composition shown by carbon of known organic derivation, Rankama concluded: "Geological evidence and trace-element determinations make probable the division of carbon in these samples into organic and inorganic groups; the mass spectrometric C^{12}/C^{13} determinations furnish *definite proof* of this and also *final proof of the organic nature* of the *Corycium* which thus is a real fossil of the late Archean time, *the oldest ever recorded with definite certainty*" (emphasis mine). This conclusion was later reaffirmed in a discussion entitled *Corycium Resuscitatum* (3), in which Rankama considered certain aspects of the problem that had been discussed by others.

Since that time the fossil status of *Corycium* appears to have been generally accepted as established, and indeed has become such a commonplace that one finds this conclusion cited without critical comment in almost any review article or text one encounters in the geochemical literature (e.g. 1, 4, 5, 6). Such notoriety is not unnatural considering that most of the geological record is a paleontological vacuum; scientists abhor a vacuum of this sort, the more so since the time of occurrence of life on the earth is an important datum for geochemistry. Moreover, if the above conclusion is correct one could apply the criterion to the genesis of any graphite deposit; recently Wickman and von Ubisch (7) reasoned conversely that graphite derived from carbonate deposits should have an isotopic composition close to that of the carbonate and greatly different from organic material and thus decided that a certain graphite deposit was not of organic origin.

I have recently discussed these conclusions elsewhere (8) and it is sufficient here to point out that the fundamental assumption that isotope ratios characterize a material as to source is certainly invalid in this case. The isotopes of the light elements are fractionated in chemical reactions and unless one can say that graphite of a certain isotopic composition cannot be produced *by any other method* than one involving organic activity, the argument is clearly hopeless. We are not able to calculate fractionation factors for reactions involving graphite (8) and thus we cannot know that C^{12} enriched graphite cannot be formed in some way from C^{13} enriched carbonate or any other inorganic carbon, even if we knew the temperatures and specific reactions that must have obtained. Moreover, even if we knew the equilibrium constants for the isotopic exchange reactions we still could not rule out non-equilibrium processes. The same argument applies to graphite that falls in the composition range of carbonates with respect to origin from an originally organic source. Finally, both Trofimov (9) and I (8) have found that the carbon in igneous rocks has the same range of composition as Rankama's samples; if this is primary igneous carbon the argument becomes even more

hopeless. Of course one can reply that specific circumstances in a certain instance seem to rule out all other modes of origin; in such a case one is simply reverting back to the geological evidence and there is no necessity even to discuss the isotopic composition. As I pointed out previously (8) we must hope that geological evidence can help us evaluate the isotopic variation in graphite, and not the reverse.

The point I wish to make in this communication is that there should be some method of informing readers of review articles as to whether or not the reviewer has enough acquaintance with the field to do a competent job of critical evaluation. For example, reviews might be labeled *clerical* reviews and *critical* reviews. In the clerical review the emphasis must be on complete coverage of the field; the object is to inform the reader as to what actual work has been done, what data are available, and where the data may be found in the literature. There is no attempt to resolve conflicting viewpoints on the evaluation of the data; the reader is simply referred to the original literature and his own judgment. On the other hand the critical review represents an attempt to evaluate the status of knowledge in the field. The bad data are discarded, conflicting viewpoints are critically discussed, and the emphasis is on interpretation and integration. This type of review must in general be left to active workers in the field; since no one is infallible there will of course be occasional mistakes in both judgment and interpretation. I can only regard such a situation as healthy, for the discussion and controversy that are the breath of science are stirred by criticism.

Certainly both types of reviews are needed; however, they should be clearly differentiated for the reader. In the article under discussion (1) the reviewer has in effect added a certain implied validity to Rankama's thesis by stating it as a general fact in his own terms; to be consistent with the overall tone of the review the thesis would better have been referred directly to Rankama and cited as Rankama's opinion. It is unfortunate that in many review articles the distinction between the clerical type and critical type is not made clear; thus what is meant to be a clerical review sometimes becomes inadvertently an incompetent critical review that misinforms the general reader. Most especially in geochemistry do we need competent critical reviews; we may well agree with Rankama when he states (3): "The geologist of today will find himself steering an uneasy course between Scylla and Charybdis—physics and chemistry—and, unless he is able to fight against those perils with their own weapons, he is a goner, being ultimately confined only to the realm of field geology."

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UNIVERSITY OF CHICAGO,
June 12, 1953.

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REVIEWS

Geological Maps. By G. W. CHIPLONKER. Pp. iv + 92. Dastane Brothers Home Service, Ltd., Poona, 1953. Price, Rs. 7–8–0.

This long awaited and much needed book will be gratefully welcomed both by the teacher and students. Indian students of geology, unlike their counterparts of the Western World, are greatly handicapped for want of suitable books quoting Indian examples. A beginning has, however, been made. It is hoped that suitable books by competent persons in other branches as well will follow ere long.

The book, by the head of the Department of Geology of the University of Sangor, is divided into eleven chapters and four useful appendices. The first chapter gives a concise idea of the three main types of rocks, the standard stratigraphical scale and the corresponding Indian equivalents. The second chapter deals with topography, its representation and interpretation. The next three chapters deal with the relationship of dip, strike, and outcrop, and graphical and trigonometrical solutions of all the important dip-strike problems. Chapter six is entirely devoted to folds, and the seventh chapter deals concisely with unconformity. The eighth chapter on "Faults" is excellently written, covers twenty pages, and is profusely illustrated. The ninth chapter deals with inliers and outliers, and the tenth chapter is devoted to forms assumed by igneous rocks. The last chapter deserves special mention. It deals with the most important aspect, viz., the interpretation of geological maps. Some idealized and a few actual maps have been illustrated for this purpose. In the appendices the author gives the use of the rectangular protracter, explains the Maclaren's Rule and includes not only a table of natural sines, tangents, etc., but also two tables (i) showing variation of dip with change of direction and (ii) depth of stratum below horizontal surface for various distances and dips. Barring "Geology of India" this is the only book on any branch of geology, specially written for Indian students. It will be a refreshing change for Indians to go through a book in which examples illustrative of certain geological features from his own country are quoted. The book is printed on good art paper and by Indian standards is excellent in format; besides it is also moderately priced.

C. RAJAGOPALAN.

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Volcanoes as Landscape Forms. By C. A. COTTON. Pp. 416; figs. 223. John Wiley & Sons, Inc., New York, 1953. Price, $9.00.

This volume is the revision of a first edition that appeared in 1944. In it the author states that an approach to vulcanism may be made through a study of petrology or geomorphology and in this book the latter approach is adopted. The book is concerned with landforms developed through vulcanic activity and with their geomorphic development, rather than with theories of vulcanism and petrogenesis. Like its predecessor this book deals with types of eruption, lava volcanoes, volcanic heat, pumice volcanoes, Vesuvius, and its cycle of activity.

In Part II, he deals with volcanic landscapes considering domes and cones of basaltic lava, lava plateaux, block lavas, viscid lavas, ash showers, ash built stratified

cones, and submarine eruptions, as well as craters, calderas, dissected basalt plateaus and erosion and destruction of volcanic mountains. The whole subject matter is covered rather completely and the book is nicely illustrated with many sketches and a number of photographs. For anyone interested in geomorphology, he must of course be familiar with this book. It is written also for laymen as well as the student of geomorphology and in Professor Cotton's customary lucid style. As the author states in his preface, there is nothing in the book that can not be understood by an intelligent person who is willing to try. He says that his chapters 2, 4, 6 and 7 can be digested without special strain. These chapters deal with "A country below sea level," "Deep furroughs on the continents and in the deep sea," "The root of a mountain chain," "A trip on a volcano," "Life and its evolution." There are seven chapters altogether. Chapter 5, and chapter 3 which is "Across the Swiss Alps," may require as he says a little more knowledge of geology or geomorphology. As the titles will illustrate, the author deals with separate individual problems. "The country below sea level," for example, deals only with the knowledge of the changes of sea level, the depths of the ocean, factors that relate to it, and is followed by a list of references. "Across the Swiss Alps" is really a chapter on the structure of the Swiss Alps. Some of it would be just a little bit complicated for the lay reader. "The root of a mountain chain" deals with the problems that relate to the origin of mountains and the formation of deep basins. The chapter "A trip on a volcano" is an interesting study of the life history of a volcano. In his chapter 7, "Life and its evolution," he seems to part a little bit from the general character of the others as it is a rapid survey of organic evolution.

The book is nicely written, fairly well illustrated, and certainly will be of interest to all students of geology.

Synthetic Products and Refinery Processes. The Science of Petroleum, Volume V, Part II. Pp. 329; pls.; figs.; tbls. Oxford University Press, New York, 1953. Price, $35.00.

This sizable addition to "The Science of Petroleum" consists of 28 papers written by 54 authors, both British and American, covering the newer knowledge of the technology of Petroleum. Part I of Volume 5, dealing with crude oils, was earlier reviewed in this JOURNAL by Wallace Pratt. It is expected that a third and final Part will be published to complete Volume 5.

Section I of this Part II deals with synthetic production, such as polymerization, chemicals for synthetic rubbers, the manufacture of organic chemicals, nitroalkanes, carbon black and surface active agents. This covers 97 pages.

Section II has 5 main divisions as follows: Distillation, Refinery Processes, Cracking, Hydrogenation and Dehydrogenation, and Alkylation, followed by an Index of Subjects and Names. Each section has several subdivisions.

The subjects treated deal with new material within the industry since 1937, and also bring up to date subjects covered in earlier volumes. This volume brings together by outstanding authors a great mass of information widely scattered in many technical journals. It is a fitting companion to its predecessors of the Science of Petroleum.

Evolution of the California Landscape. By NORMAN E. A. HINDS. Pp. 240; figs. 156; maps. Bull. 158, Div. of Mines, Dept. of Natural Resources, San Francisco, 1952.

The interesting story in this book is told as much by photographs and drawings as by text. Indeed, it appears to be more than half illustrations, and excellent ones

too. A brief introduction is followed by the treatment of eleven separate provinces of ranges, valleys, deserts, and plateaus, and lastly of the sea floor. For each province there is given the geographic features, evolution of the land forms, and glaciation and volcanism if there was any. Various outstanding individual features are also described and pictured. The remarkable illustrations are carefully chosen.

The book is written in language that the non-geological traveller can understand. All geologic terms used are carefully explained. In a way it is an elementary text book but was prepared for use in the schools of the State and for those who travel in the State. However, it will also serve as a reference book for elementary geology and geomorphology students.

Geological Survey of Great Britain. By SIR EDWARD BAILEY. Pp. 278; figs. 38. Thos. Murby & Co., London, 1953. Price, $4.00.

This book is an interesting and humanistic story of the development of a geological survey, and of a geologic map of Great Britain. The author starts at the beginning in 1835 under De la Beche and carries it to the end of World War II. This embraces a period when many new developments in geology took place—glaciation, large-scale tectonics, microscopic petrology, evolution, graptolite zoning, radioactivity, age determination and the major development of economic geology. These concepts were taken up within the Survey and the Survey developed around them. The author weaves these into his story, which, in a way, is a history of modern geology. It is not the story of the Survey alone but of the development of geologic thought and practices. It is a book all geological students will want to read.

BOOKS RECEIVED.

FRANK G. LESURE.

U. S. Geological Survey—Washington, D. C., 1953.

Prof. Paper 233-E. Lower Tertiary Crinoids from Northwestern Oregon. RAYMOND C. MOORE AND HAROLD V. VOKES. Pp. 113–147; pls. 11; figs. 13. Price, $1.00.

Prof. Paper 238. Geography, Geology, and Mineral Resources of the Ammon and Paradise Valley Quadrangles, Idaho. GEORGE R. MANSFIELD. Pp. 92; pls. 2; figs. 27. Price, $2.00. *Supplement to earlier studies, supplying new information and additional data on phosphate reserves.*

Prof. Paper 243-E. Mollusks from the Pepper Shale Member of the Woodbine Formation McLennan County, Texas. LLOYD WILLIAM STEPHENSON. Pp. 56–67; pl. 1. Price, 25 cts.

Prof. Paper 243-G. Auditory Region in North American Fossil Felidae: Its Significance in Phylogeny. JEAN HOUGH. Pp. 95–115; figs. 9. Price, 20 cts.

Prof. Paper 247. Pegmatite Investigations, 1942–1945, Black Hills, South Dakota. LINCOLN R. PAGE AND OTHERS. Pp. 228; pls. 45; figs. 37; tbls. 4. Price, $3.50. *Descriptions, maps, and diagrams of deposits of mica, beryl, lithium, tantalum and feldspar.*

Prof. Paper 249-A and 249-B. Callovian (Jurassic) Ammonites from the United States and Canada. Pt. 1, Western Interior United States; Pt. 2, Alaskan Peninsula and Cook Inlet Regions. RALPH W. IMLAY. Pp. 108; pls. 55; figs. 9. Price, $1.75.

Prof. Paper 251. Geology and Mineral Deposits of Jumbo Basin, Southeastern Alaska. GEORGE C. KENNEDY. Pp. 46; pls. 7; figs. 41. *Discussion of the contact metamorphism, geomagnetic surveys, magnetite deposits, and iron ore reserves of part of Prince of Wales Island.*

Prof. Paper 254-A. American Upper Cretaceous Echinoidea. C. WYTHE COOKE. Pp. 44; pls. 16; fig. 1. Price, $1.00.

Bull. 982-C. Limonite Deposits Near Scappoose, Columbia County, Oregon. PRESTON E. HOTZ. Pp. 75–93; pls. 5; figs. 4. Price, 65 cts. *Limonite formed by intense chemical weathering of basalt and deposited in basins and streamchannels during interruption in extrusion of Columbia River basalts.*

Bull. 982-E. Iron-Ore Deposits of the Iron Mountain District, Washington County, Idaho. J. HOOVER MACKIN. Pp. 121–151; pls. 6; fig. 1. *Iron-ore deposits include magnetite and specularite replacements in Permian marble associated with tactite and sulfide deposits around the borders of granitic rocks, and early red hematite deposits formed by weathering processes where a Tertiary erosion surface cut sulfide deposits.*

Bull. 982-F. Magnetite Deposits of the Sterling Lake, N. Y.–Ringwood, N. J., Area. PRESTON E. HOTZ. Pp. 153–244; pls. 5; figs. 26; tbls. 10. Price, $1.25. *Magnetite deposits believed formed by metasomatic replacement of pyroxene amphibolite. Report includes descriptions of individual mines.*

Bull. 988-E. Radioactivity in Some Oil Fields of Southeastern Kansas. GARLAND B. GOTT AND JAMES W. HILL. Pp. 69–120; pls. 10; figs. 5; tbls. 10. Price, $1.00. *Study of abnormally high concentration of radium in precipitates and drill samples.*

Bull. 988-F. Uranium-Bearing Deposits West of Clancey, Jefferson County, Montana. WAYNE A. ROBERTS AND ARTHUR J. GUIDE 3D. Pp. 69–87; pls. 4; figs. 3. *Uranium deposits occur in silicified fracture zones in quartz monzonite and related rocks of the Boulder batholith.*

Bull. 989-B. Gypsum Deposits Near Iyoukeen Cove, Chicagof Island, Southeastern Alaska. G. M. FLINT, JR., AND E. H. COBB. Pp. 27–37; pl. 1; figs. 3. Price, 30 cts.

Bull. 993. Refractory Clay Deposits of South-Central Colorado. KARL M. WAAGÉ. Pp. 104; pls. 5; figs. 17; tbls. 7. *Description of refractory and semi-refractory clays in the Purgatoire formation and Dakota sandstone.*

Bull. 988-A. Zinc-Copper Deposit at Tracy Arm Petersburg District, Alaska. H. R. GAULT AND R. E. FELLOWS. Pp. 13; pls. 3; figs. 2. Price, 35 cts.

Bull. 1002-A. Geophysical Abstracts 152, January–March, 1953. MARY C. RABBITT, S. T. VESSELOWSKY AND OTHERS. Pp. 61. Price, 25 cts. *Abstract numbers 14184–14388.*

Water Supply Paper 1132. Quality of Surface Waters of the United States, 1948. Pts. 1–6. Pp. 515; fig. 1. Price, $1.50.

Water Supply Paper 1136. Native and Contaminated Ground Waters in the Long Beach-Santa Ana Area, California. A. M. PIPER, A. A. GARRETT AND OTHERS. Pp. 320; pls. 19; figs. 29; tbls. 33. Price, $1.50. *Ocean waters, connote waters in rocks of Tertiary age, oil-field brines and oil-field wastes, and fluid industrial wastes form potential saline contaminants.*

Water Supply Paper 1137-E. Floods of 1950 in Southwestern Oregon, Northwestern California. Pp. 413–503; pl. 1; figs. 12; tbl. 1. Price, 65 cts.

Water Supply Paper 1140. Geology and Ground Water Resources of the Egbert-Pine Bluffs, Carpenter Area, Laramie County, Wyoming. J. R. RAPP, D. A. WARNER AND A. M. MORGAN. Pp. 67; pls. 3; figs. 4; tbls. 9.

Water Supply Paper 1167. Water Levels and Artesian Pressures in Observation Wells in the United States in 1950. Pt. 3, North-Central States. Pp. 198; figs. 11. Price, 50 cts.

Water Supply Paper 1190. Ground-Water Conditions in Artesian Aquifers in Brown County, Wisconsin. W. J. DRESCHER. Pp. 49; pls. 7; figs. 13; tbls. 9.

Circ. 208. Stratigraphic Sections of the Phosphoria Formation in Idaho, 1947–48, Pt. 1. V. E. MCKELVEY, D. F. DAVIDSON, F. W. O'MALLEY AND L. E. SMITH. Pp. 49; pl. 1; figs. 2.

Circ. 209. Stratigraphic Sections of the Phosphoria Formation in Montana, 1947–48. R. W. SWANSON, W. R. LOWELL, E. R. CRESSMAN AND D. A. BOSTWICK. Pp. 31; fig. 1.

Circ. 210. Stratigraphic Sections of the Phosphoria Formation in Wyoming, 1947–48. V. E. MCKELVEY, L. E. SMITH, R. A. HOPPIN AND F. C. ARMSTRONG. Pp. 35; pl. 1; fig. 1.

Circ. 211. Stratigraphic Sections of the Phosphoria Formation in Utah, 1947–48. L. E. SMITH, G. F. HOSFORD, R. S. SEARS, D. P. SPROUSE AND M. D. STEWART. Pp. 48; pl. 1; fig. 1.

Circ. 237. Monazite Deposits of the Southeastern Atlantic States. JOHN B. MERITE, JR. Pp. 31; pl. 1; figs. 2.

Circ. 262. Stratigraphic Sections of the Phosphoria Formation in Idaho, 1947–48, Pt. 3. F. W. O'MALLEY, D. F. DAVIDSON, R. A. HOPPIN AND R. P. SHELDON. Pp. 43; figs. 2.

Circ. 271. A Preliminary Determination of the Age of Some Uranium Ores of the Colorado Plateaus by the Lead-Uranium Method. L. R. STIEFF, T. W. STEARN AND R. G. MILKEY. Pp. 19; figs. 7; tbls. 9. *Data suggests late Cretaceous or early Tertiary age for uranium introduction.*

Circ. 272. Concentration of Germanium in the Ash of American Coals: Progress Report. TAISIA STADNICHECKO, K. J. MURATA, PETER ZUBOVIC AND ELIZABETH L. HUFSCHMIDT. Pp. 34; figs. 11; tbls. 16. *Germanium most highly concentrated in bright woody coal (vitrain).*

Circ. 277. Preliminary Report on the Comet Area, Jefferson County, Montana. GEORGE E. BECRAFT. Pp. 8; pl. 1; fig. 1.

Circ. 278. Preliminary Report on Uranium Deposits in the Miller Hill Area, Carbon County, Wyoming. J. D. LOVE. Pp. 10; pl. 1.

Circ. 279. Reconnaissance for Radioactive Deposits in the Ruby-Poorman and Nixon Fork Districts, West-Central Alaska, 1949. MAX G. WHITE AND JOHN M. STEVENS. Pp. 19; figs. 4; tbls. 10.

Circ. 281. Bibliography of U. S. Geological Survey Trace Elements and Related Reports. DIANE CURTIS AND SHIRLEY S. HOUSER. Pp. 21. *Compilation of reports made available to the public, through May 31, 1953.*

Circ. 286. An Occurrence of Autunite, Lawrence County, South Dakota. R. C. VICKERS. Pp. 5; figs. 2; tbls. 2.

Circ. 291. A Uranium-Bearing Rhyolitic Tuff Deposit Near Coaldale, Esmeralda County, Nevada. D. C. DUNCAN. Pp. 7; figs. 4.

Circ. 294. Results of Reconnaissance for Radioactive Minerals in Parts of the Alma District, Park County, Colorado. C. D. PIERSON AND Q. D. SINGEWALD. Pp. 9; pl. 1; figs. 2; tbls. 2.

The Future of Birmingham Red Iron Ore, Jefferson County, Ala. Pt. 1—History and Ore Reserves. J. R. THOENEN AND AVERY H. REED, JR.; **Pt. 2—Concentration.** B. H. CLEMMONS. Pp. 71; figs. 13; tbls. 14. Bureau of Mines Rept. of Inv. 4988, July, 1953.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1953.

Fourteenth Semiannual Rept. of the Atomic Energy Commission. Pp. 98; figs. 5.

RME-2. Exploration Drilling Techniques on the Colorado Plateau. JOHN P. KELLOG. Pp. 25; pls. 4; figs. 3.

RME-3040. Uranium Occurrence in Asphaltites: Tech. Rept.—June 1, 1952 to March 31, 1953. THOMAS D. O'BRIEN. Pp. 6; fig. 1.

RME-3042. Annual Rept. for June 1952 to April 1, 1953. Pt. 1—Fracture Studies in the Zuni and Lucero Uplifts, New Mexico. WALTER H. BUCHER. Pp. 12.

RME-3043. Primary Sedimentary Trend Indicators as Applied to Ore Finding in the Carrizo Mountains, Arizona and New Mexico. Pt. 1—Tech. Rept. for April 1, 1952 to March 31, 1953. WILLIAM LEE STOKES. Pp. 45; figs. 16.

RME-3044. Annual Rept. for July 1, 1952 to March 31, 1953. JOHN W. GRUNER, LYNN GARDINER AND DEANE K. SMITH, JR. Pp. 58; tbls. 4. *Report includes discussion of syngenetic versus hydrothermal hypothesis of origin for Colorado Plateau uranium deposits.*

RME-3047. Petrographical Investigations of the Salt Wash Sediments. Progress Rept.—December 1, 1952 to March 1, 1953. J. S. KAHN, D. W. GROFF AND JOHN C. GRIFFITHS. Pp. 55.

RME-3048. The Synthesis of Zirconium, Thorium and Uranium Silicates. Tech. Rept. for July 1, 1952 to March 31, 1953. CLIFFORD FRONDEL AND RICHARD L. COLLETTE. Pp. 27; pl. 1; figs. 2.

RME-4007. Selected Bibliography on Uranium Exploration and the Geology of Uranium Deposits. MARGARET COOPER. Pp. 34.

RME-4016. Uranium Investigations Near Aladdin, Crook County, Wyoming. JOSEPH R. GRAY AND ANTHONY C. TENNISSEN. Pp. 13; figs. 3.

NYO-6198. Age Determination of Uranium Minerals by Pb^{210}. J. LAWRENCE KULP, WALLACE S. BROECKER AND WALTER R. ECKELMANN. Pp. 15; figs. 2.

NYO-6200. Present Status of the Lead Method of Age Determination. J. LAWRENCE KULP, GEORGE L. BATE AND WALLACE S. BROECKER. Pp. 40; figs. 10; tbls. 9.

RMO-66. Uranium in the Dirty Devil Shinarump Channel Deposit. GEORGE W. BAIN. Pp. 40; figs. 8; tbls. 5.

American Geological Institute, National Academy of Sciences-National Research Council—Washington, D. C., 1953.

Geological Abstracts. Pp. 100. *First issue containing abstracts from journals of member societies of A.G.I., to be followed by quarterly issues in March, June, September, and December.*

Rept. No. 8. Departments of Geological Science in Educational Institutions of U. S. and Canada. Pp. 171. Price, $1.00.

Brown Coal, Its Mining and Utilization. P. H. HENDERSON, Editor. Melbourne University Press; New York: Cambridge University Press, 1953. Pp. 351. Price, $7.50. *Contains eleven papers on the nature, distribution, mining, and various industrial uses of brown coal.*

Colliery Surveying. R. MCADAM. Oliver and Boyd, Edinburgh, 1953. Pp. 146. Price, 12/6 net. *Includes chapters on chain and compass surveying, levelling, areas and volumes, dip and fault problems, and theodolite surveying.*

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California Journal of Mines and Geology, Vol. 49, No. 3. Pp. 263–337; pls. 6; figs. 28. *Flotative Properties of Titanium Minerals in Oleate Solutions, by V. S. Pradhan and D. W. Mitchell; Mines and Mineral Resources of Kings County, California, by Charles W. Jennings; Adsorbent Clays in California, by Richard S. Lamar.*

Bull. 134. Geological Investigations of Chromite in California, Pt. II—Coast Ranges, Chap. 2—Chromite Deposits of the Southern Coast Ranges of California. GEORGE W. WALKER AND ALLAN B. GRIGGS. Pp. 39–88; pls. 8; figs. 5; tbls. 3. Price, $1.25.

Bull. 134. Geological Investigations of Chromite in California, Pt. III—Sierra Nevada, Chap. 5—Chromite Deposits in the Northern Sierra Nevada, California. GARN A. RYNEARSON. Pp. 171–323; figs. 10; tbls. 18. Price, $2.00.

Bull. 160. Geology of the Saltdale Quadrangle, California. T. W. DIBBLEE, JR.; **Mineral Deposits of Saltdale Quadrangle.** T. W. DIBBLEE, JR., AND T. E. GAY, JR. Pp. 65; pls. 11; figs. 5.

Bull. 161. Mineralogy of the California Glaucophane Schists. GEORGE SWITZER. Pp. 51–70; figs. 5.

Special Rept. 29. Geology and Ore Deposits of the Afterthought Mine, Shasta County, California. JOHN P. ALBERS. Pp. 18; pls. 6; figs. 9. Price, 75 cts.

Special Rept. 30. Geology of the Southern Part of the Quail Quadrangle, California. CHARLES W. JENNINGS. Pp. 18; pls. 2; figs. 16. Price, 75 cts.

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Special Rept. 32. Geological Investigations of Strontium Deposits in Southern California. CORDELL DURRELL. Pp. 48; pls. 9; figs. 12. Price, $1.25. *Description of celestite and strontianite deposits.*

A Review of the Geology and Activities in the Uinta Basin. A. M. CURRENT. Quarterly of the Colorado School of Mines, Vol. 48, No. 3, Golden, 1953. Pp. 36; pls. 6. Price, 50 cts.

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Rept. of Inv. 166. Siliceous Materials of Extreme Southern Illinois. J. E. LAMAR. Pp. 39; figs. 17; tbls. 11. *Geology, mining processes and industrial uses of microcrystalline silica, novaculite, ganister, siliceous shale and chert.*

Rept. of Inv. 167. Crystal Chemistry and Differential Thermal Effects of Dolomite. W. F. BRADLEY, J. F. BURST AND D. L. GRAF. Pp. 207–217; figs. 6.

Bull. 78. Minable Coal Reserves of Illinois. GILBERT H. CADY. Pp. 137; pls. 8; figs. 37.

Kansas University and Geological Survey—Lawrence, 1953.

Bull. 102, Pt. 1. Petrographic Study of Southeastern Kansas Coals. WILLIAM W. HAMBLETON. Pp. 76; pls. 12; figs. 5; tbls. 11.

Bull. 103. Oil and Gas Developments in Kansas During 1952. W. A. VER WIEBE, E. D. GOEBEL, J. M. JEWETT AND A. L. HORNBAKER. Pp. 201; pls. 2; figs. 5; tbls. 67.

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Upper Marmaton Strata in Western and Northern Missouri. WALLACE B. HOWE. Missouri Geological Survey, Rept. of Inv. 9, Rolla, 1953. Pp. 29; pls. 3.

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Circ. 9. Ohio's Mineral Resources and Publications of the Ohio Geological Survey. Pp. 47.

Rept. of Inv. 19. Oil and Gas Well Drilling Statistics. Compiled by ROBERT L. ALKIRE. Pp. 68.

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Bull. M 36. Surface and Subsurface Structure of the Driftwood Quadrangle. ROBERT C. BOLGER AND HARRY V. GOUSE. Pp. 32; pls. 3; fig. 1; tbls. 2.

Progress Rept. 143. Oil and Gas Developments in Pennsylvania in 1952. CHAS. R. FETTKE. Pp. 30; pls. 3; figs. 4; tbls. 3.

University of Texas Bureau of Economic Geology—Austin, 1953.

Rept. of Inv. 11. Correlation Between Surface and Subsurface Sections of the Ellenburger Group of Texas. LEO HENDRICKS. Pp. 44; pls. 6; fig. 1; tbls. 2.

Publ. 5305. The Geology of Henrys Chapel Quadrangle, Northeastern Cherokee County, Texas. H. B. STENZEL. Pp. 119; pl. 1; figs. 57. Price, $3.50.

Uranium-Vanadium Deposits of the Thompsons Area, Grand County, Utah. WM. LEE STOKES. Utah Geological and Mineralogical Survey, Bull. 46; Salt Lake City, 1953. Pp. 51; pls. 2; figs. 12; tbl. 1. Price, $1.00.

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Mem. 268. Dezadeash Map-Area, Yukon Territory. E. D. KINDLE. Pp. 68; pls. 7. Price, 75 cts.

Mem. 269. Goldfields-Martin Lake Map-Area, Saskatchewan. A. M. CHRISTIE. Pp. 126; pls. 7; figs. 15; tbls. 6. Price, 75 cts.

Mem. 270. Weldon Bay Map-Area, Manitoba. J. KALLIOKOSKI. Pp. 80; pls. 5; figs. 13. Price, 75 cts.

Mem. 271. Batty Lake Map-Area, Manitoba. D. S. ROBERTSON. Pp. 55; pls. 4; figs. 2. Price, 75 cts.

Bull. 25. Interpretations of the Structural Geology of the Sherridon-Flin Flon Region, Manitoba. J. KALLIOKOSKI. Pp. 18; figs. 9. Price, 50 cts.

Bull. 26. Bedrock Geology of the Seaboard of Labrador Between Domino Run and Hopedale, Newfoundland. E. H. KRANCK. Pp. 44; pls. 5; figs. 5.

Annual Rept. Fiscal Year 1951–52. Pp. 108. Price, 50 cts.

The Canadian Mineral Industry in 1950. Pp. 148. Price, 25 cts.

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Manitoba Department of Mines—Winnipeg, 1953.

Publ. 52–2. A Geological Reconnaissance of the Wolverine and Caribou Rivers. G. A. RUSSELL. Pp. 10; pl. 1.

Publ. 52–4. Geology of the Western Bear Lake Area. CLIFFORD M. ALLEN. Pp. 19.

Preliminary Report on Ground Investigations of Aeromagnetic and Aeroradioactive Anomalies in the Espanola-Lake Huron Area. W. D. HARDING. Pp. 9.

Quebec Department of Mines—Quebec, 1953.

The Mining Industry of the Province of Quebec in 1951. Pp. 102.

P. R. 256. Sintering and Melting Points of Iron Ores from New Quebec. JEAN LANEUVILLE. Pp. 10; pl. 1.

P. R. 276. Disintegrability of Iron Ores from New Quebec Compared with Standard Ores. JEAN LANEUVILLE. Pp. 18; figs. 2; tbls. 8.

P. R. 277. Porosity and Adsorptivity in Iron Ores from New Quebec Compared with Standard Ores. JEAN LANEUVILLE. Pp. 18; figs. 4; tbls. 4.

SOCIETY OF ECONOMIC GEOLOGISTS

PROGRAM AND ABSTRACTS OF PAPERS TO BE PRESENTED TO THE JOINT MEETING OF THE SOCIETY OF ECONOMIC GEOLOGISTS AND THE GEOLOGICAL SOCIETY OF AMERICA TO BE HELD AT TORONTO, CANADA, NOVEMBER 9–11, 1953.

MONDAY MORNING, ROOF GARDEN.

ECONOMIC GEOLOGY.

Cyril Knight and Carl Tolman, *Cochairmen.*

(After each paper 5 minutes is allowed for discussion.)

1. 9:00 Edward Sampson * and M. E. Hriskevich: *Cobalt-arsenic minerals associated with aplites at Cobalt, Ontario, Canada.*
2. 9:15 E. P. Kaiser: *Geologic associations of niobium in the United States.*
3. 9:35 William C. Kelley: *Approaches to the study of lead-zinc gossans.*
4. 9:55 R. E. Wallace,* S. W. Hobbs and A. B. Griggs: *Structural setting of the Coeur d'Alene mining district, Idaho-Montana.*
5. 10:15 F. B. Whiting: *Geology and ore controls at the Guadalupe Mine, Newvo Leon, Mexico.*
6. 10:30 Harrison Schmitt: *Notes on the silica problem of the bedrock ore deposits.*
7. 10:50 Robert B. Howe: *Pegmatitic lithium deposits of Canada.*
8. 11:10 R. W. Boyle: *The geochemistry and origin of the gold-bearing quartz veins and lenses of the Yellowknife Greenstone Belt.*
9. 11:30 Walter S. White: *Copper shales of Germany and Michigan.*
10. 11:45 W. D. Holser and C. J. Schneer: *Deposition of high temperature nonmagmatic magnetite.*

MONDAY MORNING, PARLOR D.

ECONOMIC GEOLOGY (SEG COAL COMMITTEE).

W. L. Whitehead and C. G. Ball, *Cochairmen.*

(After each paper 5 minutes is allowed for discussion.)

1. 9:00 M. B. B. Crockford: *Geology of coal in Alberta, Canada.*
2. 9:20 Donald K. Norris: *Structural conditions in coal mines of the Southern Canadian Cordillera.*
3. 9:35 A. Ignatieff: *Outbursts in coal mines.*
4. 9:55 Lewis H. King: *Occurrence, distribution, and weathering of pyrites in coals from the Sydney coal field, Nova Scotia.*

* Indicates speaker.

5. 10:15 P. A. Hacquebard * and K. C. Lahiri: *Petrographic examination of washed, screened, and crushed samples of coal from the Sydney and St. Rose coal fields, Nova Scotia.*
6. 10:35 Kenneth E. Clegg: *Metamorphism of coal by peridotite dikes in southern Illinois.*
7. 10:55 Grace Somers: *Comparison of megascopic and microscopic examinations of coal.*
8. 11:15 H. D. Smith: *Conferences at Crystal Cliffs, Nova Scotia, on the origin and constitution of coal.*

MONDAY AFTERNOON, CONCERT HALL.

ECONOMIC GEOLOGY.

E. S. Moore and William James, *Cochairmen.*

(After each paper 5 minutes is allowed for discussion.)

1. 2:00 Paul W. Richardson: *Geology of the Mindamar mine, Stirling, Nova Scotia.*
2. 2:15 K. D. Watson: *Paragenesis of the zinc-lead-copper deposits at the Mindamar mine, Nova Scotia.*
3. 2:25 C. S. MacKenzie: *Base-metal deposits of Northern New Brunswick.*
4. 2:40 A. M. Bell * and F. J. Scott: *Alteration associated with ore at Gaspe copper mines.*
5. 2:55 A. E. Moss (for Staff of Iron Ore Co. of Canada): *Geology and ore deposits of central portion of Labrador Peninsula* (GAC).
6. 3:10 Peter Price: *Wall-rock alteration in northwestern Quebec* (GAC).
7. 3:25 D. R. Lochhead: *Review of the Falconbridge ore deposit, Ontario, Canada.*
8. 3:40 W. L. Jarvis: *Geology of the Campbell Red Lake mines.*
9. 3:55 C. P. Jenney: *Coppermine River area, Northwest Territories, Canada* (GAC).
10. 4:10 Q. C. Whishaw: *Jersey Dodger lead-zinc ore bodies, Salmo, British Columbia.*
11. 4:25 Clive W. Ball: *Emerald, Feeney, and Dodger tungsten ore bodies, Salmo, British Columbia.*
12.

TUESDAY AFTERNOON, CONCERT HALL.

ECONOMIC GEOLOGY.

George Langford and Arthur H. Lang, *Cochairmen.*

(After each paper 5 minutes is allowed for discussion.)

1. 2:00 Robert J. Wright: *Lithologic ore controls in sandstone-type uranium deposits, Colorado Plateau.*
2. 2:20 Walter H. Bucher * and Arthur K. Gilkey: *Fracture pattern and uranium ore of the Zuni Uplift, New Mexico.*

* Indicates speaker.

3. 2:40 Warren I. Finch: *Distribution of uranium deposits in the Shinarump conglomerate of the Colorado Plateau.*

4. 3:00 Leo J. Miller: *Ore textures of uraninite and associated minerals from the Colorado Plateau uranium deposits.*

5. 3:15 J. B. Mawdsley: *Radioactive, pronouncedly differentiated pegmatite sill, Lac La Ronge district, Northern Saskatchewan, Canada.*

6. 3:35 L. W. Parkins: *Geology of the Radium Hill uranium mine, South Australia.*

7. 3:50 Roger A. Blais: *Structural and decrepitation features of the gold mineralization at the O'Brien Mine, Quebec, Canada.*

8. 4:10 F. Gordon Smith: *Variation of low-temperature decrepitation of quartz from the No. 6 vein of the Lamaque gold mine, Quebec, Canada.*

9. 4:30 Harry V. Warren * and Robert E. Delavault: *Biochemical Investigations in Eastern Canada.*

WEDNESDAY AFTERNOON, DINING ROOM 7.

ECONOMIC GEOLOGY (SEG COAL COMMITTEE).

W. V. Searight, *Chairman.*

2:00 Business Meeting of the Coal Committee.

THE EMERALD, FEENEY AND DODGER TUNGSTEN ORE-BODIES, SALMO, BRITISH COLUMBIA.

CLIVE W. BALL.

c/o Canadian Exploration Limited, Salmo, B. C., Canada.

The scheelite ore bodies occur within limestone and skarn country-rock and are localized where such beds conformably overlie argillite and form trough structures by contact with intrusive granite.

Faulting is found along the main granite contact, and minor faults which strike sub-parallel to the troughs have exercised a definite structural control. It is believed that mineralization, arising from deep within the granite, was distributed by medium of quartz-tourmaline veins and siliceous veins traversing breccia zones and faults. Tungsten solutions were also concentrated at nodal points by offshoot dykes of granite and pegmatite running out from the granite into the beds of limestone and skarn.

Four distinct types of host rock are recognized: skarn, limestone, quartz and greisenized granite. Pyrrhotite and biotite are generally present in the first three types and a close association is shown between scheelite and quartz in all four types. Most of the scheelite is finely disseminated and distinguished only by use of the ultra-violet lamp. A little powellite and molybdenite appear close to the underlying argillite and at the granite contact.

The orebodies are lenticular and tend to thin and splay out on the flanks. They are Contact Metamorphic in origin. In close proximity to the ore zones the granite is greisenized and tourmaline is conspicuous.

Hydro-thermal action is indicated by sericitization of the felspars and chloriti-

* Indicates speaker.

zation of the biotite. Two generations of quartz are indicated and it is possible that there are two generations of scheelite.

Major production to-date has come from the Emerald trough which is over 4,000 feet in length.

ALTERATION ASSOCIATED WITH ORE AT GASPE COPPER MINES.

A. M. BELL AND F. J. SCOTT.

The geology of the copper deposits now being developed by Gaspe Copper Mines in the Gaspe Peninsula is summarized in this paper with particular attention being paid to metamorphism in the host rocks associated with ore replacement.

The ore occurs in faulted and gently folded Palaeozoic sediments and seems to derive from a buried stock of granite. The best orebody is a replacement in a limestone bed and lies up dip from the intrusive. The deeper end of this ore approaches to within half a mile of the granite and the upper end is one and one-quarter miles away. Two types of alteration on the area are in evidence. One type is a general metamorphism of a block with a surface extent of two square miles that has bleached the rocks and developed silicates with only minor changes in chemical composition. This alteration is earlier, has no direct connection with ore replacement and seems an effect of heat from the granite. Another type of alteration is intimately connected with ore and involves a decided change in chemical composition. This alteration seems produced by solutions, a late phase of which accomplished ore replacement. The limey beds have been converted to silicates by the addition of silica and the loss of lime while the less limey rocks have been silicified. Ore coincides with the skarn alteration in those areas in which some unreplaced calcite remains in the silicate rock. These areas are in the portions furthest out from the intrusive centre and on the flanks of the skarn.

The Gaspe ore is a hydrothermal replacement whose further study should throw light on the controls and temperatures of deposition of other deposits occurring in sedimentary rocks.

STRUCTURAL AND DECREPITATION FEATURES OF THE GOLD MINERALIZATION AT THE O'BRIEN MINE, QUEBEC.

ROGER A. BLAIS.

Quebec Dept. of Mines, 35 d'auteuil, Quebec, P. Q.

Quartz veins of distinctive structural pattern and characteristic wall-rock alteration form the environment of gold deposition at the O'Brien mine. Fracturing and shattering of vein quartz afforded minute openings for migration of auriferous solutions and the late gold was concentrated in, or near, structures favouring such brecciation of vein quartz. The ore-shoots have almost vertical pitch, with a great pitch length in comparison to stope length.

The observed relationships of minor-scale fracturing of vein quartz to gold deposition and to planes of secondary liquid inclusions form the basis for this extensive study of vein quartz. The decrepitometric data for 1,000 quartz samples indicates relationships between liquid inclusion, decrepitation and distribution of ore values. Auriferous vein quartz is characterized by decrepitation temperatures from 75° C to 120° C, whereas barren quartz starts to decrepitate above 130° C. Trend lines of low decrepitation temperatures correspond to ore-chimneys. It is contended that barren sections of quartz veins have not been reworked during the gold stage and, consequently, do not show low temperature decrepitation, which appears to be due to characteristic liquid inclusions trapped in intra-mineralization fractures of vein quartz.

THE GEOCHEMISTRY AND ORIGIN OF THE GOLD BEARING QUARTZ VEINS AND LENSES OF THE YELLOWKNIFE GREENSTONE BELT, NORTHWEST TERRITORIES, CANADA.

R. W. BOYLE.

Geological Survey of Canada, Ottawa.

The economic gold quartz veins and lenses occur within shear zones in steeply dipping greenstones (amphibolites) of Precambrian age. The shear zones consist of chlorite schist which has been highly altered in the vicinity of the quartz veins and lenses. The zones of alteration enveloping the quartz bodies include an adjacent carbonate-sericite zone and an outer chlorite-carbonate zone which grades into the chlorite schist of the shear zone. Throughout the shear zones extensive chlorite-carbonate areas are present which show no intimate spacial relationship to the quartz bodies.

Chemical analyses of samples taken across the strike and down the dip of the shear zones show that there is a marked loss of SiO_2 in the chlorite schist of the shear zones when compared with the amphibolite of the wall rocks. This loss increases in the chlorite-carbonate zones and reaches a maximum in the carbonate-sericite zones. In one shear zone where the quartz lenses occur above extensive carbonate-chlorite schist portions a marked decrease in SiO_2 with depth is evident.

Graphs of the chemical analyses across the width of the alteration zones indicate that the loss of SiO_2 is compensated for by the addition of CO_2 and H_2O. The shape of the SiO_2 concentration line, exhibiting a low adjacent to quartz bodies and increasing in value toward the wall rock, indicates that the SiO_2 has migrated toward the present site of the quartz bodies.

The chemical evidence strongly suggests that CO_2 and H_2O from mineralizing solutions displaced SiO_2 from the alteration zones and chlorite-carbonate areas of the shear zones, and that this SiO_2 migrated toward dilation areas within the shear zones where it was deposited as quartz veins and lenses.

FRACTURE PATTERN AND URANIUM ORE OF THE ZUNI UPLIFT, NEW MEXICO.

WALTER H. BUCHER AND ARTHUR K. GILKEY.

Department of Geology, Columbia University, New York 27, New York.

In 1951, under the Atomic Energy Commission's auspices and under the direction and partly in company with Walter H. Bucher, Arthur Gilkey undertook to study the joints and faults of the Zuni Uplift as part of a comparative study of the fracture patterns of domed areas. In addition to the Zuni area, Gilkey studied two elongated narrow folds formed by horizontal movement (Virginia Appalachians and Marathon basin) and one domed by intrusion from below (Maze Arch, Henry Mountains). His observations bore out conclusions derived from the literature, that in laterally compressd folds the chief faults and dominant joints cut the axis at high angles (70–90°). In updomed areas, they parallel the axis.

The relatively flat top; the shape due to more or less well defined flexures; and faults and flexures that cut the uplift suggest that the Zuni Uplift is the result of differential upward movement along faults cutting the crystalline basement.

The angular relations that exist among the faults and flexures are those obtained on the surface of a cube of clay deformed by gentle compression. The upward movement that changes the fractures into "faults" is inherent in the process.

In each structural unit of the uplift, the dominant joints in the sediments tend to parallel the nearest controlling fault or flexure, as if the differential movement

had stretched the sedimentary cover. Since this movement originates at depth, the fault displacement must have started there and advanced toward the surface localizing the stresses in the sediments above.

The association of the uranium ore with fluorite replacing the Todilto limestone in the Grants region and the elongation of the ore-rich areas, delineated by drilling, parallel to the local fracture pattern, suggest a causal connection between ore and fractures.

*METAMORPHISM OF COAL BY PERIDOTITE DIKES IN SOUTHERN ILLINOIS.**

KENNETH E. CLEGG.

Illinois Geological Survey, Urbana, Illinois.

While studying the effects of igneous intrusions on bituminous coal in southern Illinois, a method was developed whereby a close approximation could be made of the temperature involved during the intrusion.

Field investigations in a strip mine where a mica-peridotite dike and adhering natural coke had been uncovered showed that the widths of zones of metamorphosed coal are small, being in one instance only 12 to 14 inches adjacent to a dike 18 inches thick, that the zone is usually wider adjacent to larger dikes, but that no direct correlation exists between the size of the intrusive and the width of the metamorphosed zone.

Through differential thermal analyses of natural coke samples taken at measured intervals from the contact of an 18-inch thick dike, and comparison of the results with those obtained from analyses of normal coal samples pre-heated to known temperatures, cooled, and then re-run, estimates were made of temperatures to which coal at various distances from the dike had been heated.

At more than four or five inches from the contact, coal was insufficiently altered to permit estimates by thermal methods, and thin section studies were used.

A maximum temperature of 600 degrees centigrade immediately adjacent to the dike is estimated, with rapid decrease outward.

GEOLOGY OF COAL IN ALBERTA.

M. B. B. CROCKFORD.

c/o J. C. Sproule & Associates, 901 8th Ave. W., Calgary, Alberta.

Coal in Alberta is found in the following five geological formations: Kootenay and Luscar formations of Lower Cretaceous age, Belly River and Edmonton formations of Upper Cretaceous age, and the Paskapoo formation of Lower Tertiary age. These coals are mined in the eastern Rocky Mountains, the foothills belt and the plains. In general, mountain coal has semi-anthracite and bituminous rank; foothills coal is bituminous; and plains coal is subbituminous and lignite.

According to the last coal survey made in 1947, Alberta has a recoverable reserve of 23,937,150,000 tons. Minable coal, that is, coal in seams three feet or more in thickness and at depths of less than 1,000 feet on the plains and 2,500 feet in the foothills, is 47,874,300,000 tons, made up of 34,437,630 tons probable coal and 13,436,560,000 tons possible. These reserves constitute 48% of the total reserves of Canada.

Detailed surveys of coal seams on the plains show that their maximum extent is 4 to 5 miles in a direction normal to old shore lines. Some seams have been traced for greater distances parallel to old shore lines. It was further observed that the number of coal seams in the geologic section varies greatly within the same

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formation. Consequently, the tracing and correlating of coal seams without continuous outcrop or good marker control can lead to error. The correlation of coal seams in faulted areas as in the foothills and mountains is especially difficult.

DISTRIBUTION OF URANIUM DEPOSITS IN THE SHINARUMP CONGLOMERATE OF THE COLORADO PLATEAU.

WARREN I. FINCH.

U. S. Geological Survey, Box 360, Grand Junction, Colorado.

On the Colorado Plateau the Upper Triassic Shinarump conglomerate contains many important uranium deposits. A reconnaissance study of the deposits, made to appraise the potentialities of areas underlain by the Shinarump conglomerate, yielded tentative conclusions.

The Shinarump consists mainly of light-colored sandstones and conglomerates in channel fills and even-bedded layers. Uranium minerals impregnate the rock. Deposits range range in size from a few tons to many thousand tons and seem to be localized mainly in three belts.

In Monument Valley, northeastern Arizona and southeastern Utah, a belt of favorable ground at least 4 miles wide and 40 miles long trends northwestward. The deposits are localized in deep channels, which also trend northwestward. In White Canyon, southeastern Utah, a belt of favorable ground averaging 5 miles in width and about 30 miles in length trends northeastward. The deposits in this belt occupy shallow channels. In central and eastern Utah, significant deposits and geologically favorable ground are alined in a belt 10 to 20 miles wide and about 100 miles long. The deposits occur in even-bedded sandstone in the eastern and western parts of the belt and along the transition zone of facies change from coarse to fine sediments in the central part of the belt. An altered zone, colored purple and white, in the Moenkopi formation and Shinarump conglomerate has an areal distribution that roughly coincides with this favorable belt.

These belts, representing about 10 percent of the areal distribution of the Shinarump, are more favorable for prospecting than the remainder of the region. Even in these favorable belts, deposits are sparsely scattered.

PETROGRAPHIC EXAMINATION OF WASHED, SCREENED AND CRUSHED SAMPLES OF COAL FROM THE SYDNEY AND ST. ROSE COALFIELDS, NOVA SCOTIA.[1]

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The coal seams of the Sydney coalfield are in several ways extraordinary, since no great differences occur either in rank or petrographic composition. Over a stratigraphic interval of 3800 feet the volatile matter content varies from 36 to 42% (mineral matter free). All 12 seams, with the exception of one, may be classed as very bright coal containing between 73 and 84% vitrain plus bright clarain. However, each seam contains dull coal horizons high in opaque matter and/or exinite. Concentration of these dull parts, by washing, screening and crushing *was the objective of this study.*

Coals were examined from the Emery and Harbour seams of the Sydney coalfield, and from No. 5 seam of the St. Rose field.

[1] Published by permission of the Deputy Minister of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Canada.

The petrographic analyses were carried out with an integrating stage, using polished specimens of ground coal, mounted in lucite. Accuracy tests on this method were highly satisfactory.

Results obtained are:

1. Washed coal is lower in opaque matter than non-washed coal, since opaque matter together with shaly impurities concentrates in the fractions of higher density.
2. Concentration of opaque matter by screening alone depends on the amount and distribution of this material in the seam. Fusain is always higher in the finest fraction.
3. A notable concentration of dull coal is obtained by pounding and subsequent screening. Grinding instead of pounding does not give results. Only by taking advantage of the natural differences in strength of the coal components can concentrations be obtained.

DEPOSITION OF HIGH TEMPERATURE, NON-MAGMATIC MAGNETITE.

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Reduction of contamination and of analytical errors corrects previous values of magnetite solubility, from equilibration in Morey bombs. In pure water at 180–510 degrees and 490–1280 bars, solubility is less than 0.03 ppm iron, the sensitivity of colorimetric analysis of the solution. The large quantity of water necessary to form known "hydrothermal" deposits with such small solubilities indicates the magnetite was not precipitated from neutral solutions. A few experiments suggest a similar low limit of solubility in alkaline solutions.

Magnetite is appreciably soluble at 25 degrees in dilute HCl solutions. With magnetite in a platinum-lined bomb at 390 degrees and 425 bars, we found less than 0.03 ppm iron in solution at 10^{-5} N HCl, but more than 5 ppm at 10^{-3} N. The latter is considerably greater than the volatility of ferric chloride, in the presence of a large proportion of water, as extrapolated from Shafer's data, suggesting solvent action by water. This transition from water solubility to halide gas mixtures is now being investigated.

These data indicate possible deposition of iron oxides when a halide-rich fluid enters a region of higher water content. Coupled with the recent proof by Vinogradov of deposition when halides contact calcite, it emphasizes the importance of deposition by change of composition rather than temperature or pressure.

OUTBURSTS IN COAL MINES.

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This paper is confined to the treatment of occurrences of varying degrees of suddenness, encountered normally only in coal mines, when relief of stress is accompanied by an outflow of gas contained mainly in the coal.

The "outburst" phenomenon is defined in relation to other forms of relief of stress and the two factors that appear to be dominant in these occurrences, that of change of stress equilibrium and of the association of gas with the coal, are discussed.

These occurrences are of particular interest to the geologist: in the classical

development they have always been associated with areas of pronounced structure. Examples from several countries are briefly given.

The present state of knowledge of this problem is reviewed indicating that while practical precautionary methods in the mine have reduced hazards to human life, a clear conception of the causes of these occurrences has not yet been established, principally on account of the inconclusive evidence as to the state of association of gas and coal.

The studies, underground, of stress considerations and the laboratory work on the coal-gas association, inaugurated by the Canada Department of Mines and Technical Surveys, are described in the form of a preliminary progress report.

GEOLOGY BY CAMPBELL RED LAKE MINES LIMITED.

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Rock types in the mine area are andesite, Campbell diorite, rhyolite, syenite porphyry dikes and three zones of altered rock.

Different phases of the altered zones have been mapped as a single unit.

The northernmost altered zone traces out an S-shaped fold which moves southwest at depth. Associated west-raking ore bodies are of two kinds. (1) Quartz carbonate veins occupy shears which strike north-west, dip vertical or steeply south, and trend parallel to the fold axes. (2) Irregular ore bodies trend in a northerly direction and occupy tension breaks believed consequent to increased acuteness of folding at depth.

Most of the south zone ore occupies a compound shear that strikes north-west and dips vertical to steeply south. At the west end, the ore terminates at the south, folded contact of the central altered zone where the contact strikes south-west and dips north-west. The east end of another vein with north-west strike and vertical dip terminates at a similarly folded bed of Campbell diorite. The folding was formerly interpreted as faulting; but beds on strike with the proposed fault are uninterrupted. Replacement bodies located north of the south zone shear rake west and cross the shear at depth. Ore moves north on the east side of a "black line" fault. Minor folds indicate that the mine is located on the south limb of a major fold which pitches steeply south-west.

THE COPPERMINE RIVER AREA, NORTHWEST TERRITORIES, CANADA.

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Exploration for copper in a region of 7,000 square miles south of the Arctic Ocean between west longitudes 114° and 118° has covered a period of nearly 200 years. Early efforts were confined largely to general exploration and a description of the country. Intensive prospecting of this area was undertaken by two companies in the period 1929-1931. Since 1943 information gained by further prospecting, geologic mapping and diamond drilling has added to our knowledge of the area and is set forth below.

In the Coppermine, late Precambrian sediments and volcanics rest unconformably on a basal granite. The younger rocks are separated by a disconformity into an older series of sediments—predominantly dolomites, and an overlying section of basalt and diabase flows with interbedded sandstones, shales and slates.

The area covers the southwestern portion of a large, shallow basin more than 400 miles in diameter. Northeast trending major tension faults have been traced for distances of over 50 miles and the zone of this faulting has been traced to Great Bear Lake, 100 miles to the southwest. Copper mineralization, principally primary chalcocite and bornite, is widespread in the outcrop area of the basalts of the lower Coppermine Series and is closely associated with the faults. Although no mineable ore deposits have been found to date, the total volume of copper in numerous showings throughout this region marks the Coppermine as an important area of copper mineralization.

GEOLOGIC ASSOCIATIONS OF NIOBIUM IN THE UNITED STATES.

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The element niobium is commonly referred to as columbium in commercial usage and in the older American technical literature. United States niobium production, which has been small, has been from pegmatites; but placer deposits containing radioactive columbates are being developed in Idaho.

Niobium concentrations in the United States are found in the following environments: (1) pegmatites; (2) placers containing columbate minerals; (3) titanium deposits in alkalic igneous rocks, involving the minerals rutile, brookite, perovskite, and sphene; and (4) various accessory minerals—especially sphene, ilmenite, and rutile—in igneous and metamorphic rocks.

Rutile and brookite from the alkalic complex of Magnet Cove, Arkansas, and rutile from the alkalic rocks of the Marfa area in western Texas contain between 1 and 5 percent Nb. These deposits have recently been studied by the U. S. Geological Survey. Rutile from other sources generally contains less than 0.1 percent Nb. Ilmenite associated with anorthosite in Virginia, New Jersey, Quebec, and elsewhere contains generally less than 0.01 percent Nb. Perovskite from Magnet Cove contains much more niobium than that from the similar alkalic complex at Iron Hill, Colorado. Sphene in Arkansas syenite, the parent rock of the bauxite deposits, contains as much as 0.6 per cent Nb, and is apparently the source of the niobium in the bauxite. The Geological Survey is studying accessory minerals of ore or potential ore to confirm or refute the possibility of other concentrations of niobium. It is suggested that mining companies should investigate the niobium content of their titanium-bearing minerals.

APPROACHES TO THE STUDY OF LEAD-ZINC GOSSANS.

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Current approaches to the reconstruction of lead-zinc gossans into their original primary ores include many not yet available during the early studies of Locke, Blanchard, and Boswell. Several of these were selected and tested in the field and laboratory. Of considerable value was the quantitative consideration of gossan porosity using both standard measurements and modified Rosiwal counts. Color criteria proved of local value but could not be transferred from one district to another. As all gossan "limonites" so far tested are goethite, the mineralogy of the hydrous iron oxides proved of little aid in predicting primary mineralogies or in distinguishing transported from indigenous "limonite." Processes and rates of

oxidation of lead and zinc ores were reviewed by experimentation and could be clearly related to grain size and E.M.F. effects. The formation of zinc carbonates as against zinc silicates in the oxide zones seems to be determined by climatic factors.

OCCURRENCE, DISTRIBUTION AND WEATHERING OF PYRITE IN COALS FROM THE SYDNEY COALFIELD, NOVA SCOTIA.[1]

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The nature and occurrence of pyrites in coal is studied by the polished-surface technique using high power, oil immersion objectives.

Pyrites occurs in greatest abundance in finely disseminated form, although lenses and bands, sulphur balls, and veins along cleats and joints are well known.

Disseminated pyrite consists of cubic, globular, prism-like, stellated, and irregular shaped particles. These forms are found as individual particles, clusters, aggregates and massive patches. The prism-like and stellated forms have been identified as marcasite by means of x-ray analysis.

The amount of disseminated pyrite varies both horizontally and vertically. The vertical changes in concentration may be either sharp or gradational. In any event, well defined benches of high sulphur coal are often evident in the seams.

In some instances, benches and bands high in marcasite occur and occasionally extend laterally for considerable distances. One exceptional occurrence can be traced laterally for a distance of 11 miles. Successive layers of marcasite and pyrite can possibly be accounted for by changes in the pH of the swamp waters at the time of deposition.

The particle size of the disseminated pyrite generally falls between 10 and 50 microns, but particles only a small fraction of a micron in diameter sometimes occur in abundance. The rapid oxidation of pyrite in coal can be related to particle size alone. Particles below the range of 1–3 microns weather rapidly while particles larger than this critical range do not weather under laboratory conditions.

A REVIEW OF THE FALCONBRIDGE ORE DEPOSIT.

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Falconbridge Mine is situated on the outer edge of the norite-micropegmatite irruptive near its south east corner. The ore deposit varies from 5,500 to 6,500 feet in length and is presently known to the 4,000 ft. horizon. It is sheet-like in form and coincides for the most part with the contact of the norite and the older Keewatin greenstones, conforming in strike and dip with this contact. The ore zone is localized along this section of the contact by a strong regional shear coinciding with the contact. This shear appears to be pre-norite in age with post-norite movement. Subsidiary breaks from the main shear produce ore swells which extend into the adjoining walls for relatively short distances. It is concluded that the shear zone provided the channel, or travelway, for the transfer of the ore from its source upwards to its resting place, and also, that the shear provided the permeable zone necessary for the deposition of the ore deposit. It is also concluded that the ore and the pre-ore norite originated from the same magma source.

[1] Published by permission of the Deputy Minister of Scientific Services, Department of Mines and Technical Surveys, Ottawa, Canada.

BASE METAL DEPOSITS OF NORTHERN NEW BRUNSWICK.

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Occurrences of base and other metals have long been known in Northern New Brunswick. Within the past year or so deposits of mineable grade with tonnages to the order of several tens of millions have been discovered and are still undergoing exploration. Intensive prospecting, mainly by ground geophysical methods with guidance by airborne magnetometer surveys, is underway throughout the region.

The ore deposits are in a region of typical Appalachian formations and structures of early to mid-Palaeozoic age.

An areal and probably structural, if not genetic, relationship of the ore bodies to intrusions of Devonian granite is apparent.

Some deposits are related to a system of northeasterly and northwesterly shear directions and associated tension fractures. The newly discovered large deposits, trending nearly north-south, are related to broad flexures.

Shearing and fracturing have been localized along contacts of competent intrusions, massive flows, or iron formation, with incompetent argillites, tuffs, or schisted flows.

The major deposits are massive pyrite bodies with pyrrhotite locally prominent. Sphalerite, galena and chalcopyrite are intimately mixed with and along veinlets in the iron sulphides. A silver content is general. Texture is fine-grained and suggestive of replacement.

Other deposits range from disseminations to massive injections and replacements and from quartz-arsenopyrite-gold veins, through pyrrhotite-chalcopyrite and sphalerite-galena-pyrite deposits with mainly quartz gangue or accompanying silicification and fine to medium and/or coarse-grained sphalerite-galena veins with calcite gangue.

A RADIOACTIVE, PRONOUNCEDLY DIFFERENTIATED PEGMATITE SILL, LAC LA RONGE DISTRICT, NORTHERN SASKATCHEWAN.

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Five miles east of Hunter bay, Lac La Ronge is an irregular pegmatite sill including metamorphosed sediments. It is composed of three facies; an upper margin two inches thick of fine grained (¼ to 1 inch) chiefly white oligoclase plagioclase and quartz, next is ten feet, or more, of coarse (8 inches) crystals chiefly salmon-pink potash feldspar and white plagioclase, both graphically intergrown with quartz; and, a central band four feet, or more, thick of salmon-pink microcline-peerthite crystals up to two feet long with interstitial glassy quartz and a little muscovite.

The central two facies are not radioactive, but the outer selvedge and immediately adjacent coarse mica schist are notably so in places. At a gable-like part of the upper contact of the sill, over a length of eight feet, and over a width of one to four inches numerous uraninite crystals up to one inch in diameter have been obtained. This uraninite is low in thorium. Another part of the upper contact has a concentration of thorium crystals. A scintillometer survey obtained a number of above-background readings elsewhere near the inferred upper contact of the sill.

Evidently the radioactive material tended to concentrate next to the hanging wall. Presumably it migrated there before the crystallization of the sill was far advanced.

ORE TEXTURES OF URANINITE AND ASSOCIATED MINERALS FROM THE COLORADO PLATEAU URANIUM DEPOSITS.

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Uraninite in the ore deposits of the Colorado Plateau is present as a replacement mineral. It replaces the clay cement of the quartz grains, the quartz overgrowths, asphaltite, organic matter, and in some cases sulphide minerals. The exsolution texture of chalcopyrite and bornite indicates deposition at a high temperature. A comparison of the large amount of the alteration at the Marysvale uranium deposit and the low amount of alteration of the Plateau deposits suggests a low temperature deposition for the Plateau deposits.

THE GEOLOGY AND ORE DEPOSITS OF THE CENTRAL PORTION OF THE LABRADOR PENINSULA.

THE STAFF OF THE IRON ORE COMPANY OF CANADA.

PRESENTED BY A. E. MOSS.

Within the Labrador Peninsula in northeastern Canada is a belt of rocks tens of miles wide and hundreds of miles long known as the "Labrador Trough." Some 8,000 square miles of the "trough" is described in this paper based on the work done by a large number of geologists while employed by privately financed exploration companies during the period from 1936 to 1953.

The "Labrador Trough" is an intricately folded and faulted geosynclinal segment consisting of a great variety of sedimentary and volcanic rocks which have been cut by intrusives ranging in composition from serpentinites to granites. These rocks are considered to be late precambrian and in places rest unconformably on an early precambrian, gneiss complex. The stratigraphy in some sections has been fairly well established although correlation throughout the area will require much additional work.

Economically, the most important rocks are the iron bearing sedimentary members or "iron formation" which throughout the area are believed to occur at the same stratigraphic horizon. The high-grade, iron ore is secondary and most is caused by the removal of silica and the addition of iron to a formation which originally contained about 30 percent iron. However, some ore extends into adjacent formations that contained little or no iron originally, indicating that much iron has been transported. It is not considered necessary to postulate that hydrothermal solutions have played a role in the formation of this iron ore.

STRUCTURAL CONDITIONS IN COAL MINES OF THE SOUTHERN CANADIAN CORDILLERA.

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Geological Survey of Canada, Ottawa.

Fault and drag-fold patterns in the lower Cretaceous, bituminous coal seams of the Crowsnest and Cascade coal areas may be interpreted by the mechanics of shear-thrusting. Gentle flexing of the overriding masses was affected through similar folding for the combined series of competent and incompetent units. Consequent alternate stretching and compression of the coal-bearing sequences resulted in the development of a profusion of extension and contraction faults of small stratigraphic

throw (generally less than ten feet), and a sheared condition within the coal. Frictional resistance retarded those beds in the overthrust masses closest to the thrust planes so that in every instance the upper beds moved slightly farther to the east relative to those below them. Consistent drag-fold patterns within the coal were the result.

That these minor faults are apparently genetically related to the regional structures of the coalfields is borne out by the common trends of the major and minor structures, the directions of slickensiding, and the almost complete absence of these minor faults in the relatively undisturbed seams of the Alberta Syncline.

THE GEOLOGY OF THE RADIUM HILL URANIUM MINE, SOUTH AUSTRALIA.

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The Radium Hill Mine, originally worked on a minor scale for its radium content, has been intensively tested by drilling, sampling and exploratory development over the past ten years, and is now a significant producer of uranium ore. The ore mineral, which is the titanium uranium complex davidite, occurs in association with rutile, ilmenite bronze biotite and quartz in a series of sub-parallel lodes which are late stage replacements in shear planes. The shears are located near the axial plane of a regional dome in early Precambrian metasediments. The strike of the shears is slightly undulatory, and dips range from 40° to 70°.

The distribution of the ore within the lode channels is in irregular shoots though with some suggestions of over-all pitch.

The area has been a locus for numerous phases of igneous activity some of which are considered significant in the localization of ore.

WALL ROCK ALTERATION IN NORTHWESTERN QUEBEC.

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Two main types of alteration accompany the copper-zinc-gold deposits of the Noranda and Bourlamaque districts. Lavas (rhyolites and andesites) and associated minor intrusives (acid to basic) were widely sericitized and silicified. On this phase is imposed a later high magnesian (chloritic) alteration.

In time and space the first is associated closely with the early pyrite-sphalerite mineralization. The second with later pyrrhotite-chalcopyrite-magnetite. Gold and associated tellurides (the last mineralization) carry no outstanding alteration features but appear most prominently in the magnesian rich areas. Some orebodies show all three types (Horne (Noranda) and Quemont); others, two (Waite-Amulet, East Sullivan); a third group, only one (MacDonald, Golden Manitou).

The minerals most closely associated in time and space with the copper mineralization are various chlorites. Progress has been made in the recognition of the variations exhibited by this group and their relative diagnostic value in ore finding has been partly solved. Also of some value are secondary amphiboles, ottrelite, hsingerite, etc.

One group of orebodies (Waite-Amulet) is accompanied by a suite of alteration products higher in magnesia than the average. A pervasive spotted sericite-biotite-cordierite alteration (dalmatianite) is cut by a cordierite rich type with numerous anthopyhllite rosettes and finally a chlorite-cordierite rock which is generally nearest to ore.

Study of a considerable thickness of rocks overlying ore has been possible in some cases. It has been found that the escape channels above and beyond an orebody are comparatively minute and can easily be overlooked. The zoisite-clinozoisite-epidote group have considerable diagnostic value in such cases.

GEOLOGY OF THE MINDAMAR MINE, STIRLING, NOVA SCOTIA.

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The mineral deposit of Mindamar Metals Corporation occurs in a northeasterly striking shear zone that is sub-parallel to several major faults. The shear is parallel to a steeply to vertically dipping series of acidic volcanics. Rhyolite tuff in the shear is replaced by carbonate and quartz which form at least two large lenticular bodies. Within the carbonate bodies, the ore shoots, which vary in grade from 7–20% combined zinc, lead and copper, lie along several steep veins. The position of the ore bodies within the veins is determined by several factors of which the most apparent is the presence of inclusions of unreplaced rhyolite tuff adjacent to the veins.

The workings of the previous operators are in a carbonate body 1,000 feet long and up to 150 feet wide. Surface drilling has revealed an additional ore-bearing carbonate body along strike to the north and ore grade materials, as yet undefined in outline, to the south.

PEGMATITIC LITHIUM DEPOSITS OF CANADA.

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Geological Survey of Canada, Ottawa, Ontario.

Pegmatitic lithium deposits of interest in Canada occur in the Yellowknife-Beaulieu region, Northwest Territories; in the Cat Lake-Winnipeg River region, and the East Braintree and Herb Lake districts, Manitoba; and in the Preissac-Lacorne region, Quebec.

The pegmatites are heterogeneous, lithium-rich, granitic pegmatites in which zones are by far the most important structural units. These pegmatites are marginal and exterior pegmatites occurring in middle-to high-grade metamorphic rocks and intrusive rocks, and related spatially, and possibly genetically, to granites containing 20 to 40 percent potash feldspar and 20 to 40 percent albite or oligoclase. In two of the districts, there is a regional zonation of granitic pegmatites about bodies of granite with the lithium-rich pegmatites occurring farthest from the granite. In some of the deposits, greatly elongated spodumene crystals occur oriented parallel to one another.

Lithium minerals found in the pegmatites include spodumene, amblygonite, lepidolite, zinnwaldite, a variety of other lithium-bearing micas, lithiophilite, and petalite, of which spodumene is by far the most important. In most of the deposits, the spodumene is too fine-grained to be hand-cobbed.

Although there is no production of lithium minerals in Canada at present, several deposits have been diamond drilled and extensive milling and metallurgical tests have been made on spodumene-bearing pegmatite by the Mines Branch, Ottawa, and other agencies. Considerable tonnages of pegmatite containing from 10 to 30 percent spodumene are inferred, but the deposits are not being developed because of uncertainties concerning the market for lithium products in Canada, and the transportation factor.

COBALT–ARSENIC MINERALS ASSOCIATED WITH APLITES, AT COBALT, ONTARIO.

EDWARD SAMPSON AND M. E. HRISKEVICH.

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Minor cobalt mineralization is closely related to aplite dikes which in turn are differentiates of the Nipissing diabase sheet. Gersdorfite occurs as replacement of aplite and, in one instance in a vug filling where the mineral succession has been albite, quartz, carbonate with metallic minerals.

The relationship of this mineralization to the main mineralization of the district is discussed. It is concluded that both are related to the differentiation of a tholeiitic magma.

NOTES ON THE SILICA PROBLEMS OF THE BED ROCK ORE DEPOSITS.

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The problem of the source of the silica found as quartz, silicification and silication is a basic one in the genesis of ore deposits. In the bed rock environment does silica originate and move for distances measured in thousands of feet or even in miles, or is place of origin and migration usually limited to tens or rarely several hundreds of feet? On the answer to this question may importantly depend the final determination of the character of the ore transporting and depositing fluids. Should it be proved that most silica is limited in its distance of migration, current ideas of differentiation of a magma toward the quartz vein and epigenetic silicate deposits may be challenged.

VARIATION OF LOW TEMPERATURE DECREPITATION OF QUARTZ FROM THE NO. 6 VEIN OF THE LAMAQUE GOLD MINE, QUEBEC.

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The No. 6 vein of the Lamaque mine is one of a series of quartz veins in reverse faults which cut across the hanging wall of an intrusive pipe. Quartz from this and other veins in the mine has a low temperature stage of decrepitation. Qualitatively, the relative amount of this decrepitation increases approaching high grade gold sections. Quantitatively, the temperature of beginning of this stage of decrepitation can be contoured in the plane of the No. 6 vein, and is related to its structure.

A COMPARISON OF MEGASCOPIC AND MICROSCOPIC EXAMINATIONS OF COAL.

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Several columns of coal, previously described microscopically by means of transmitted light, were studied megascopically with the aid of a light reflected on the polished surface of the coal. The coal was prepared in the same manner that a

column of coal is prepared for microscopic study by reflected light—the column was divided into blocks, ground, and polished.

The objective of the study was to determine whether or not a dull band of coal when studied megascopically corresponded to the microscopic splint or durain, and likewise, whether or not bright bands corresponded with the microscopically bright coal. It was recognized that a certain degree of transition should occur between the bright and dull bands. Such transitions were observed megascopically, and an attempt was made to correlate such areas with semi-splint and claro-durain.

Mineral matter plays an important role in the dullness or brightness of coal, and because of the abundance of this impurity, in many cases, the lustre of an otherwise bright band is partially lost. In such cases, the correlation between megascopic and microscopic analyses, in terms of bright and dull coal, is non-existent. However, there are cases, in which mineral matter is not present, where megascopic dullness does not always correspond with microscopic lustre. It is therefore suggested that the dullness or brightness of a coal may not be determined by one microscopic maceral, such as opaque matter or vitrinite, but perhaps by an association of macerals, as well as by the amount of ash in the coal.

STRUCTURAL SETTING OF THE COEUR D'ALENE MINING DISTRICT, IDAHO–MONTANA.

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U. S. Geological Survey, Spokane, Wash.

The Coeur d'Alene mining district is situated in an intensely deformed structural knot in Precambrian metasedimentary rocks of the intersection of a northeastward-trending and a northwestward-trending structural element in the Northern Rocky Mountain province. Monzonitic and syenitic stocks, together with large folds and faults, constitute the northeastward-trending element; the Osburn fault, which is at least 150 miles long, dominates a group of folds and faults trending northwestward.

The veins are grouped in zones that trend essentially northwestward, subparallel to the Osburn fault. The district has been subjected to repeated deformation by stresses of different orientations; and as a result reverse faults, strike-slip faults, and normal faults have developed.

SOME BIOGEOCHEMICAL INVESTIGATIONS IN EASTERN CANADA.

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During the past five years the authors have investigated the practicability of using biogeochemical methods in prospecting for buried ore bodies in Eastern Canada.

On the basis of more than five thousand analyses "normals" are tentatively suggested for copper and zinc in most of the more common species of trees and lesser plants including Jack Pine (*Pinus Banksiana*), Black and White Spruce (*Picea mariana* and *Picea glauca*), Tamarack (*Larix laricina*), Balsam (*Abies balsamea*), Poplar (*Populus tremuloides*), White Birch (*Betula papyrifera*), and Labrador Tea (*Ledum groenlandicum*).

The influence of underlying mineralization has been found to parallel that observed in the Pacific Northwest.

In the light of data presently available variations above "normal" of more than fifty percent in copper and thirty percent in zinc may be considered possibly anoma-

lous, and more than one hundred percent in copper and fifty percent in zinc probably anomalous.

The most important conclusions are that:

1) With reasonably propitious conditions practically all trees or lesser plants are capable of reflecting buried mineralization.

2) There is no direct relationship between the metal content either of dry plant or ash and the metal content of the underlying mineralization.

3) With present techniques biogeochemistry can only, except under unusually favourable circumstances, yield useful results where muskeg or overburden is less than thirty feet thick.

4) Just as geologists can point to metallogenetic provinces so the biogeochemists can outline trace element provinces.

PARAGENESIS OF THE ZINC–LEAD–COPPER DEPOSITS AT THE MINDAMAR MINE, NOVA SCOTIA.

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The mine is in Richmond County, Cape Breton Island. The ore bodies are irregular lenses within a persistent, wide, steeply dipping shear zone cutting mainly sericite schist. The schist was derived principally from siliceous siltstone of probable Middle Cambrian age.

The deposits consist of extremely fine-grained pyrite and sphalerite with minor chalcopyrite, galena, and tennantite in gangue composed mainly of dolomite, magnesite, quartz, sericite, talc, and chlorite. They were formed chiefly in the following overlapping stages:

(1) Deposition of most of the fine-grained pyrite and sphalerite by replacement of sericite schist.

(2) Deposition of most of the dolomite and magnesite and some of the quartz, partly in fractures and partly by replacement.

(3) Deposition of most of the galena, chalcopyrite, and tennantite and some of the pyrite and sphalerite both in carbonates and in fine-grained pyrite- and sphalerite-bearing ore.

Some dolomite and magnesite appear from their texture to be meta-colloidal. Talc occurs chiefly as randomly oriented flakes which originated by replacement of dolomite and magnesite without recognizable change in volume.

Most of the numerous diabase dikes were intruded after deposition of carbonates and ore minerals. Several, however, were emplaced before completion of carbonate and ore deposition and have intensely carbonatized and locally mineralized margins.

Much fine-grained ore shows thin layers differing from one another in proportions of ore minerals to gangue minerals or of individual ore minerals to each other. This structure may be attributable mainly to selective replacement of relic lamination in schist and partly to replacement along closely spaced fractures.

THE JERSEY DODGER LEAD ZINC ORE BODIES, SALMO, B. C.

Q. G. WHISHAW.

Canadian Exploration Limited, Salmo, B. C.

The Jersey Lead-Zinc ore deposit is a low temperature lead-zinc replacement in dolomitic limestone. The localization of the ore is controlled by folding, and locally by brecciation and small scale faulting. The relationship of the underlying skarn bands and granite to the ore body is discussed. A possible origin for the lead and zinc in the ore is suggested.

THE COPPER SHALES OF GERMANY AND MICHIGAN.

WALTER S. WHITE.

U. S. Geological Survey, Calumet, Mich.

The copper deposits at the base of the Nonesuch shale of northern Michigan and those of the Kupferschiefer of Mansfeld, Germany, have major points of similarity. Both contain copper sulfides finely dispersed in black organic shale that overlies a thick red terrestrial sandstone or conglomerate, gray at the top. Within a zone 1 to 2 feet above this sandstone, the shale contains about 3 percent copper. Areally, individual ore concentrations are measurable in square miles, and copper occurs sporadically for scores of miles. Copper is concentrated in shallow depressions in the top of the sandstone, probably within a few miles of the ancient shoreline. Highly fractured areas may or may not be rich; some rich areas have few, if any, fractures.

Major differences are that the Kupferschiefer contains bornite and subordinate amounts of chalcocite and chalcopyrite; the sulfur-poor Nonesuch contains chalcocite, minor amounts of native copper, and traces of bornite or chalcopyrite. At White Pine, Mich., the sequence of sandstone and copper shale is repeated cyclically, with a copper-bearing siltstone above each copper-shale bed; copper per unit area is over five times that at Mansfeld. Marine limestone overlies the Kupferschiefer; gray siltstone overlies the Nonesuch deposits. Noteworthy amounts of lead and zinc are found only in Kupferschiefer.

Copper in the Nonesuch shale is believed to be an original sedimentary constituent, a view held by many students of the Kupferschiefer. In both formations the copper is closely related to sedimentary facies and only locally affected by structural features.

GEOLOGY AND ORE CONTROLS AT THE GUADALUPE MINE, NUEVO LEON, MEXICO.

F. B. WHITING.

St. Joseph Lead Company, Bonne Terre, Missouri.

Control of the sphalerite-silver-galena-barite deposits of the Guadalupe Mine, Nuevo Leon, Mexico, is exercised by structural intersections, by the differing responses to stress of the different host rocks, and by the local characteristics of deposition. The tonnage available is determined by the size of the remnants of the ore-bearing structures left by erosion.

A complex of stocks and dikes of porphyritic Laramide (?) igneous rocks, generally dioritic in composition, intruded a dome of Upper and Lower Cretaceous sediments, predominantly gray limestone and black limy shale. Faults, some flat and some moderately dipping, cut both sediments and igneous rocks. Where these faults occur completely within shale, they are merely thin sheared zones and contain only traces of the ore minerals. Faults in limestone are generally tight shears enclosing thin lenses of barite. The best ore shoots occur along the lines of intersection of flat faults with vertical dikes in shale, where pencil-shaped breccia zones were formed in which the ore minerals were deposited.

As the mineralization proceeded almost exclusively by open-space filling, the size and openness of each breccia zone determined the size and grade of that ore shoot. As most of the productive faults have closed outcrop lines around the hills, the greatest possible length of each ore shoot, and consequently an upper limit to its potential tonnage, can be found by projecting the shoot within the fault plane from the present face through the hill along the line of outcrop of its dike or simply by projecting the intersection of the fault and dike through the hill to the outcrop.

LITHOLOGIC ORE CONTROLS IN SANDSTONE TYPE URANIUM DEPOSITS, COLORADO PLATEAU.

ROBERT J. WRIGHT.

530 Orchard Avenue, Grand Junction, Colorado.

The importance of lithology in localizing uranium deposits in the Morrison formation has long been recognized. Most ore bodies have been found in sandstones more than 40 feet thick where the Salt Wash member of the Morrison has about equal proportions of sandstone and mudstone.

The discovery and development of ores in other parts of the geologic column has re-emphasized the significance of lithologic control. Although deposits are known in sedimentary formations ranging in age from Permian to middle Tertiary and are widely scattered in large parts of several states, it has been found that most ores are included in 1) fluvial sandstones, which 2) contain carbonized plant matter, 3) are not red in color, and 4) are usually arkosic.

Host rock control is particularly striking in the Permian where certain favorable but very limited arkose beds are mineralized in a thick section of barren, unfavorable eolian sandstones and red beds.

Most deposits show no apparent structural control.

The marked lithologic control suggests introduction of uranium in solution at the time of deposition of the enclosing sediments. Uranium was derived from the provenance of the sediments and was precipitated in certain favorable sedimentary environments, under reducing conditions, and in the presence of carbon. The original distribution was afterwards modified by ground water.

Sandstone uranium deposits may be the continental analogue of uranium-rich marine black shales and phosphorites. Uranium moving seaward in streams during erosion of a land mass may be fixed on the continent by certain favorable fluvial sediments to form sandstone type ore deposits; or the uranium may be carried on to the sea, for possible later fixation by certain favorable marine sediments.

Uranium-lead age determinations on sandstone ores represent an apparent contradiction to the theory.

SCIENTIFIC NOTES AND NEWS

H. G. FERGUSON ("Fergie" to the members of the USGS) was presented with a gold medal of the Distinguished Service Award, and a citation, by the Secretary of the Interior, upon his nominal retirement after 44 years of government service. The citation states in part: "An authority on the geology and mineral resources of the Great Basin, he made notable contributions to our understanding of the ore deposits of the Southwest. His extensive knowledge of foreign geology and mineral resources was invaluable to the work of the Military Geology Unit of the Survey during World War II, and his services in organizing and guiding this work with the Geological Survey deserve special mention. Dr. Ferguson's work with the Geological Survey is nationally known, and he was recently elected President of the Society of Economic Geologists. . . . His publications and original contributions to science are numerous and are evidence of an eminent career spent in the economic and military application of geology of both present and future significance."

ERNEST NEWTON PATTY assumes the presidency of the University of Alaska in September. Dr. Patty organized the University of Alaska School of Mines when he was on the faculty some years ago.

PAUL F. KERR, of Columbia University in New York, has been carrying on a geological study for the U. S. Atomic Energy Commission on Western Gold and Uranium, Inc.'s property at Marysvale, Utah.

EDWIN D. MCKEE has resigned as head of the geology department of the University of Arizona to become a staff geologist for the paleotectonic map project of the U. S. Geological Survey in Denver, Colorado.

W. B. MATHER, chairman of the minerals technology department at Southwest Research Institute, has returned from Brazil where he was studying Brazilian pegmatites.

GEORGE P. ROWE succeeds V. A. GILES as chief mining geologist for the Northern Pacific Railroad. Mr. Giles will be consulting geologist for the railroad.

OLOF H. ODMAN has received an official invitation from Nacional de Pesquisas in Brazil to lecture on Swedish ore geology in Rio de Janeiro and Sao Paulo. Professor Odman is affiliated with the Royal Institute of Technology, School of Mines in Stockholm.

ROBERT N. PARKINSON is one of a group of four experts on Canadian Precambrian geology who will study similar formations in Portuguese East Africa. Companhia Mineira do Lobito is investigating a large concession and has brought in North American engineers to carry on mining operations in the event that deposits are discovered.

THOMAS L. KESLER has joined the staff of Foote Mineral Company of Philadelphia, Pennsylvania, as their geologist.

FRED HOWELL, formerly chief geologist for Climax Molybdenum Company at Climax, Colorado, is now employed by the Haile Mining Company of Boulder City, Nevada.

JOHN E. ALLEN of the New Mexico Bureau of Mines and Mineral Resources is the new president of the New Mexico Geological Society. PHIL T. HAYES of the U. S. Geological Survey is secretary and Ross JOHNSON, also of USGS, is treasurer.

J. ROY GORDON has been elected vice-president and general manager of Canadian Operations of the International Nickel Company of Canada, Ltd. He succeeds the late LESLIE BEATTIE.

N. R. JUNNER, formerly Director of the Geological Surveys of the Gold Coast and Sierra Leone, and later consulting geologist to the Selection Trust Group, is now practicing privately as a consultant with headquarters at Haslemere, Surrey, England.

M. DUHAN GARRETY, consulting mining geologist of Melbourne, Australia, has been making a tour of mining districts in the United States and Canada.

FOLKE WALLMAN, mining engineer at the Boliden Mining Company in Boliden, Sweden, has been appointed manager of the Kantorp mines in central Sweden.

The Oregon Department of Geology and Mineral Industries announces that HOLLIS DOLE, geologist, on leave during the past two years for graduate work at the University of Utah, has returned to his post at the Portland office.

F. MCINTOSH GALBRAITH, chief geologist for Day Mines, Inc., for the past 11 years, left that position in July to join Columbia Iron Mining Co., Cedar City, Utah, where he will organize and head a geology department.

H. R. GAULT, professor of geology at Lehigh University, has taken a leave of absence to accept an appointment as executive secretary, Division of Earth Sciences, National Research Council, Washington, D. C.

TRUMAN H. KUHN, professor of mining geology, at the Colorado School of Mines, in Golden, has been appointed dean of the college's graduate division, succeeding Prof. CLARK B. CARPENTER who retired from the faculty this summer.

PAUL F. ARMSTRONG, Canadian mining geologist, left at the end of June for Turkey, as a United Nations technical assistance expert, to help the Turkish government with field work in evaluating ore deposits, especially chromite, lead, and zinc, and in prospecting for new mineral reserves.

RICHARD V. COLLIGAN, mining geologist, has been placed in charge of Cuban activities of Freeport Sulphur Co. and its subsidiary, Nicaro Nickel Co. Mr. Colligan's work will include supervision of the work at Moa Bay in Oriente Province.

JAMES W. ODELL, formerly with American Zinc, Lead & Smelting Co., is now with the St. Joseph Lead Co. at Leadwood division, Bonne Terre, Mo., as geologist.

R. D. ROBINSON has been named acting district supervisor for U. S. Geological Survey in the Arizona-New Mexico area, where he is working on DMEA projects. He was formerly chief geologist for Sunshine Mining Co. at Kellogg, Idaho.

RAYMOND BROOKS of the Rhodesia Copper Ventures, Ltd., is on leave until November, 1953, and is spending part of his time in Tucson, Arizona.

HOWARD A. MYERHOFF is now president of the Scientific Manpower Commission with offices at 1530 P Street, N.W., Washington, D. C.

JOSEPH F. HARRINGTON, U. S. Geological Survey, is in South America on a Point Four assignment for mineral resources development in Colombia and Ecuador.

ELTON A. YOUNGBERG, recently geologist with the Juneau Office of the U. S. Geological Survey in Alaska, is in Washington, D. C., with the Division of Raw Materials of the Atomic Energy Commission.

G. W. BRINDLEY, of the physics department, University of Leeds, England, has joined the staff of the Pennsylvania State College as research professor of mineral sciences.

FRANCIS BIRCH has been appointed Chairman of the Division of Earth Sciences of the National Research Council, Washington, D. C., for the year 1953–54. Dr. Birch, Sturgis-Hooper Professor of geology at Harvard University, is also chairman of the Committee on Experimental Geology and Geophysics at Harvard.

G. C. HEIKES resigned his position as chief of the Development Division, DMPA, London, in April and is now in practice as a consultant in California.

ROBERT M. DREYER has resigned as professor of geology at the University of Kansas to join the exploration staff of the Kaiser Aluminum and Chemical Corp. in Oakland, California.

H. C. GUNNING, Head of the department of geology and geography at the University of British Columbia, has been appointed Dean of the Faculty of Applied Science and will retain his position as Head of the geology and geography department. V. J. OKULITCH has been appointed Chairman of geology and J. L. ROBINSON, Chairman of geography.

THE EIGHTH PACIFIC SCIENCE CONGRESS will be held November 16 to 28, 1953, at Quezon City, Manila, Los Banos and Bagio, Philippines, under the auspices of the REPUBLIC OF THE PHILIPPINES and the NATIONAL RESEARCH COUNCIL OF THE PHILIPPINES. The geological program is under the direction of Dr. Jose M. Feliciano, University of the Philippines, Quezon City, and will include two symposia: on management and utilization of natural resources; and on geology and mining industry. Excursions are also being organized. For additional information address: The Secretary-General, 8th Pacific Science Congress, National Research Council of the Philippines, Quezon City, Philippines.

C. B. HUNT, formerly chief of the General Geology Section of the U. S. Geological Survey with headquarters in Denver, Colorado, has been appointed Executive Director of the American Geological Institute and assumed his duties on September 1, 1953.

WILLIAM B. AGOCS, formerly head of the department of geophysics of the University of Tulsa, has joined the staff of the Aero Service Corp., Philadelphia.

WESTON BOURRET is now in charge of exploration for the Utah Construction Co., with headquarters in San Francisco, and can be reached at 198 James Street, Atherton, California.

HOMER MANN, formerly with DMPA, is Denver representative of Utah Construction Co.'s exploration activities.

MARSHALL KAY has been appointed Executive Officer of the department of geology of Columbia University for a term of three years, succeeding Walter H. Bucher.

HENRY H. STORCH has been appointed chief of the Synthetic Liquid Fuels Branch of the Bureau of Mines.

CAREY CRONEIS has been appointed Provost, effective January, 1954, and Harry Carothers Weiss Professor of geology at the Rice Institute at Houston, Texas.

Following the suggestion of M. Blondel, Regional vice-president for Europe of the Society of Economic Geologists, ECONOMIC GEOLOGY is prepared to consider for translation and publication suitable articles written in French, Spanish, German or Italian. If accepted for publication these will be translated into English and published with an additional abstract in the language of the author. In order to insure contributions of merit, manuscripts should first be submitted to one of the Associate Editors of ECONOMIC GEOLOGY, or to one of the regional vice-presidents of the Society of Economic Geologists for preliminary comment and criticism. Papers submitted should preferably not exceed 30 printed pages in length. Text figures should be clearly drawn to allow reduction for publication. Explanation to be included may be in the language of the author, but space should be allowed for addition of English translation. A reasonable number of photographs and photomicrographs, pertinent to the subject, may be included.

LEWIS W. DOUGLAS, former ambassador to Great Britain, has been named chairman of a conference to be held in Washington, D. C., in the fall to evaluate the United States' mid-century position with respect to present and future use of natural resources.

C. DEWITT SMITH, superintendent of mines of St. Joseph Lead Company in Gouverneur, New York, since 1950, has been advanced to a new position in the company's New York office.

PHIL SHENON, consulting geologist in Salt Lake City, Utah, has been named to the Board of Directors of Day Mines, Inc., in Wallace, Idaho. He replaces PAUL B. JESSUP, who resigned recently to join Kennecott Copper Corporation in in New York.

CLEMENT P. POLLACK has been named exploration manager of ASARCO, with headquarters in New York. Formerly chief geologist of ASARCO's Northwestern department, last year Mr. Pollock was made assistant to vice-president R. F. GOODWIN.

THE NATIONAL SCIENCE FOUNDATION will support limited travel expenses of scientists to international meetings, including the International Union of Geodesy and Geophysics, Rome, Italy, September 16, 1954. Applications should be received before January 1, 1954.

R. M. NUGENT of the Magnolia Petroleum Company, Midland, Texas, has been appointed general chairman for the seventh annual MIDWESTERN MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS. Co-chairman is L. H. JOHNSON, Honolulu Oil Corporation, Midland, Texas. Plans are under way for the two-day meeting of oil exploration scientists in Dallas, Texas, on November 12 and 13, 1953. This meeting, which is expected to attract more than 1,000 earth scientists from Texas, New Mexico, Louisiana and Oklahoma, is sponsored jointly by the Dallas, Shreveport, Fort Worth, Tulsa, Oklahoma City and Midland sections of the SEG. The Permian Basin Geophysical Society, Midland section of the SEG, and the Dallas Geophysical Society are the host groups for this year's meeting, with members of the Midland section in charge of all arrangements.

The tentative schedule of sessions for the Geology and Geography Programs, Section E, A.A.A.S., meeting in Boston, Mass., December, 1953, is: Dec. 28, Symposium, "New England Geology"; General Geography; Symposium, "The Metropolis." Dec. 29, Symposium, "Water for Industry." Dec. 30, Symposium, "Economic Problems of New England"; General Geology; Section E Smoker, with Vice-Presidential address by A. C. Trowbridge.

The SOCIETY OF ECONOMIC GEOLOGISTS will hold joint sessions in New York with the A. I. M. E., February 15–18, 1954, at the Hotel Statler. Authors who wish to present a paper at this meeting are asked to submit titles and abstracts as soon as possible to Frank Ebbutt, Chairman S.E.G. Program Committee, 173 Glenrose Avenue, Toronto 5, Canada.

LAURENCE M. GOULD, President of Carleton College, Northfield, Minnesota, has been appointed a member of the National Science Board to replace Dr. JAMES B. CONANT, who resigned when he became U. S. High Commissioner for Germany.

THE NATIONAL SCIENCE FOUNDATION sponsored a Conference on Geology Research in Colleges at Beloit College, Wisconsin, October 30–November 1, 1953, with about 30 geologists from small geology departments in colleges throughout the country to discuss problems faced by departments having fewer than five teachers. Limited research is undertaken at many colleges because heavy teaching loads and inability of the colleges to compete with larger institutions for research funds. However, the colleges are an important source of young scientists who continue graduate work in science at larger institutions.

Reprints of "Bibliography and Index of Literature on Uranium and Thorium and Radioactive Occurrences in the United States, Pt. 2: California, Idaho, Montana, Oregon, Washington, and Wyoming," by Margaret Cooper of the Division of Raw Materials, U. S. Atomic Energy Commission, have now been made available to the public by the Geological Society of America at the price of 25 cents per copy. Remittance must accompany orders, which should be sent to: The Geological Society of America, 419 West 117th Street, New York 27, N. Y.

ROBERT A. MACKAY, of Mackay & Schnellmann, London, has just returned from professional visits to West Africa, South Africa, East Africa and Jordan. He will be attending the Annual Meeting of the Society of Economic Geologists in Toronto in November.

MISSOURI SCHOOL OF MINES AND METALLURGY in cooperation with the Missouri Coal Operators Association and the Missouri Geological Survey has arranged a Coal Conference to be held at Rolla on December 3 and 4, 1953. Details may be obtained from J. D. Forrecter, Chairman, Department of Mining Engineering, Rolla, Missouri. The following are general topics: 1, Geological Features of Coal Deposits; 2, Mining and Exploration of Coal Deposits; 3, Problems of Coal Preparation; 4, Problems of Coal Utilization and Markets.

LOUIS H. AHRENS, Assistant Professor of Geochemistry in the Department of Geology and Geophysics, Massachusetts Institute of Technology, has resigned to accept a Readership in Mineralogy at Oxford University commencing in January 1954. Professor Ahrens is widely known for his spectrochemical research on geological age and will continue similar work in England.

HERBERT E. HAWKES, recently Chief of the Geochemical Prospecting Section of the U. S. Geological Survey, Denver Federal Center, has joined the staff of the Department of Geology and Geophysics at the Massachusetts Institute of Technology as Lecturer in Geochemistry. Dr. Hawkes will conduct one course in Geochemical Prospecting and will carry on geochemical research at the Institute.

GORDON J. F. MACDONALD, Junior Fellow at Harvard University, will assume the duties of an Assistant Professor of Geology in the Department of Geology and Geophysics, Massachusetts Institute of Technology, in July 1954.